FINAL REPORT
Bilateral Comparison on Force Standard Machines
Between TUBITAK UME and SASO NMCC
(UME-KV-D3-2.10.6.b)

GULFMET.M.F - S2

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TUBITAK UME

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| Symbol       | Description                                                                 | Unit  |
|-------------|------------------------------------------------------------------------------|-------|
| $E_n$       | $E_n$ 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             | -     |
| $w(F_{nsm})$| 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                       | -     |
| $W$         | relative expanded uncertainty                                               | -     |
| $W_{CMC}$   | relative expanded uncertainty of force generated by force calibration        | -     |
|             |     machine, equivalent to CMC (calibration and measurement capability)      |       |
| $W_{nsm}$   | relative expanded uncertainty of force generated by national force Standard  | -     |
|             |     machine                                                                  |       |
| $W_{rv}$    | relative expanded uncertainty of reference value                            | -     |
| $W_n$       | 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  |
| $\Delta d$ | absolute value of relative deviation between reference value and value      | -     |
|             |     obtained in force calibration machine                                    |       |
| $\Delta d_{max}$ | absolute value of maximum relative deviation between reference value and   | -     |
|             |     value obtained in force calibration machine                              |       |
| $U_{cmc}$   | relative expanded uncertainty value of declared of laboratory               | %     |
1. Introduction

It organized a bilateral comparison on dead weight force standard machines between SASO NMCC and TUBITAK UME, in the frame of the Project of Development and Realization Measurement and Calibration System for the National Measurement and Calibration Center (NMCC) at Saudi Standards, Metrology and Quality Organization (SASO).

The bilateral comparison is performed by measuring force values taken from force standard machines located in TUBITAK UME and SASO NMCC.

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

The comparison is carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons.

The comparison was published BIMP database on GULFMET.M.F-S2 code. The comparison was used in project UME-KV-D3-2.10.6.b code.

2. Travelling Standard

There are 3 force transducers as travelling standards. Their identifications are as follows:

| No | Description              | Manufacturer                      | Capacity | Serial No |
|----|--------------------------|-----------------------------------|----------|-----------|
| 1  | Force Transfer Standard  | HBM included loading pad          | 100 kN   | 191430052 |
| 2  | Force Transfer Standard  | HBM included loading pad          | 10 kN    | 193930010 |
| 3  | Force Transfer Standard  | HBM included loading pad          | 1 kN     | 182913015 |

Table 1. Details of the travelling standards

The travelling standards were supplied by TUBITAK 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.

| Country       | Institute                                | Acronym     | Shipping Address                                                                 |
|---------------|------------------------------------------|-------------|----------------------------------------------------------------------------------|
| Turkey        | TUBITAK Ulusal Metroloji Enstitüsü       | TUBITAK 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        | 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 |
|               | Calibration Center                      |             | Abdulelah A. Binown                                                             |

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.

| Acronym of Institute | Country   | Time for measurement dates      |
|----------------------|-----------|---------------------------------|
| TUBITAK UME          | Turkey    | 02.01.2017 – 25.01.2017          |
| SASO NMCC            | Saudi Arabia | 01.03.2017 – 14.04.2017          |
| TUBITAK UME          | Turkey    | 01.05.2017 – 25.05.2017          |
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%.

| Quantity | Measurement Steps (kN) |
|----------|------------------------|
| Force    | 40 kN, 60 kN, 80 kN, 100 kN |
|          | 4 kN, 6 kN, 8 kN, 10 kN |
|          | 0.4 kN, 0.6 kN, 0.8 kN, 1 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) was established the force scale in range between 200 N and 110 kN with three different dead weight FSMs. First, FSM is a dead weight machine having maximum force of 1,1 kN, in the interval from 0.02 kN to 1,1 kN. Second, FSM is a dead weight machine having the interval from 0,1 kN to 11 kN and third, FSM is a dead weight machine having the interval from 2 kN to 110 kN. All 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). 10 kN and 100 kN dead weight type FSM of UME and 1 kN, 10 kN and 100 kN dead weight type FSM of SASO 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 Force Standard Machines of TUBITAK UME

Figure 1 shows the general view of the 110 kN/1.1 MN force standard machine. The dead weight side of the machine can be used as an independent force standard machine to generate forces of 2 kN up to 110 kN. The dead weight side has one stack of 25 weights is composed of: 4 x 1 kN; 8 x 2 kN; 1 x 3 kN; 7 x 5 kN; 5 x 10 kN, having 3 different force ranges to calibrate force proving instruments. These are 20 kN, 50 kN and 100 kN. Loading frame having a nominal value of 2 kN.
also realizes first step of force. Each one has also 10 steps with 10 % increment. The working principle and all other capabilities are the same with 11 kN dead weight machine explained above section. The lever amplification is realized with a single lever and transmission ratio of 1:10. With lever multiplication, the forces are generated of 20 kN up to 1.1 MN with force ranges 200 kN, 500 kN and 1 MN. A compression and tension space is provided on both the dead weight side and lever side.

11 kN dead weight force standard machine is given in Fig. 2. The machine can be used force range of 0.1 kN up to 11 kN. The machine is calibrated force transducers in capacity of 1 kN, 2 kN, 5 kN and 10 kN. It is suitable 10 steps with 10 % increment on each calibration according to ISO 376 standard. Its weights are produced by stainless steel disc.
7.2. The Force Standard Machines of SASO NMCC

1,1 kN dead weight force standard machine is shown in Fig. 3. The machine can be used force range of 0.02 kN up to 1.1 kN. This device is calibrated force transducers in capacity of 200 N, 500 N and 1 kN. Each one calibration has also 10 steps with 10 % increment. Its weights are produced by stainless steel disc.

Fig. 4 shows the general view of 11 kN dead weight force standard machine. The machine can be used force range of 0.1 kN up to 11 kN. This device is calibrated force transducers in capacity of 1 kN, 2 kN, 5 kN and 10 kN. It is suitable 10 steps with 10 % increment on each calibration according to ISO 376 standard. Its weights are produced by stainless steel disc.

110 kN dead weight force standard machine is shown in Fig. 5. The machine can be used force range of 2 kN up to 110 kN. This device is calibrated force transducers in capacity of 20 kN, 50 kN and 100 kN. Each one calibration has also 10 steps with 10 % increment. Its weights are produced by stainless steel disc.
Fig. 3. 1,1 kN dead weight force standard machine in SASO NMCC
Fig. 4. 11 kN and 110 kN dead weight force standard machines in SASO NMCC
7.3. The Transfer Standards

Transfer standards or travelling standards are given in table 1. There are 3 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].

![Fig. 6. Precision indicating instrument (DMP 40) and BN 100 calibrator of UME](image)

DPM 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), a BN 100 type HBM product calibrating device was used during comparison measurements (shown in Fig.6).

### 7.4. 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 five symmetrically distributed positions relative to the axis of the machine (0º, 
90º, 180º, 270º, 360º). In order to get better results, prior to start measurement cycle, the force 
transducer was loaded with maximum test load three times at the 0º position.

The measurements were carried out at (21±1) ºC 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 SASO NMCC and UME 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”.

\[
W_{CMC} = k \times \sqrt{w_r^2 + w^2(d_{fcm}) + \Delta d} \quad (1)
\]

\[
w^2(d_{fcm}) = \frac{1}{(n-1)} \sum_{i=1}^{n} ((X_{fcm,i} - X_{fcm}) / X_{fcm})^2 + w^2_{cor} \quad (2)
\]

\[
W_r = k \times \sqrt{w^2(K_n) + w^2(D)} \quad (3)
\]

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

\[
w(K_n) = \sqrt{w^2(X) + w^2(F_{nfcm})} \quad (5)
\]
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.

\( \text{UME}_i \) : UME initial measurement results
\( \text{UME}_f \) : UME final measurement results
\( \text{UME}_{\text{ave}} \) : UME average \(((\text{UME initial} + \text{UME final})/2)\) measurement results
\( \text{SASO} \) : SASO NMCC measurement results
\( \text{SASO}_{\text{corr}} \) : SASO NMCC corrected measurement results

On the tables, below formulas are used.

\[
X_{\text{AVE}} = \frac{X_1 + X_2 + X_3 + X_4 + X_5}{5} \quad (6)
\]

\[
b_{\text{BP}} = \frac{|X_{\text{max}} - X_{\text{min}}|}{X_{\text{AVE}}} \quad (7)
\]
### Table 5. 100 kN force transducer measurement results

| Force | UME 1 | UME 2 | UME AVE | SASO |
|-------|-------|-------|---------|------|
| kN    | Mean Value | Deviation | Mean Value | Deviation | Mean Value | Mean Value | Deviation |
| F     | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(X_{ave}\) | \(b_{rp}\) |
| 0     | 0.000000 | -     | 0.000000 | -     | 0.000000 | 0.000000 | -     |
| 40    | 0.798934 | 3.50E-05 | 0.798917 | 3.00E-05 | 0.798926 | 0.798907 | 3.76E-05 |
| 60    | 1.198422 | 2.59E-05 | 1.198403 | 3.09E-05 | 1.198412 | 1.198377 | 3.92E-05 |
| 80    | 1.597919 | 3.07E-05 | 1.597911 | 2.94E-05 | 1.597915 | 1.597869 | 3.82E-05 |
| 100   | 1.997423 | 3.15E-05 | 1.997460 | 1.90E-05 | 1.997441 | 1.997392 | 3.65E-05 |

### Table 6. 10 kN force transducer measurement results

| Force | UME 1 | UME 2 | UME AVE | SASO |
|-------|-------|-------|---------|------|
| kN    | Mean Value | Deviation | Mean Value | Deviation | Mean Value | Mean Value | Deviation |
| F     | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(X_{ave}\) | \(b_{rp}\) |
| 0     | 0.000000 | -     | 0.000000 | -     | 0.000000 | 0.000000 | -     |
| 4     | 0.798340 | 7.52E-06 | 0.798350 | 2.51E-05 | 0.798345 | 0.798323 | 4.38E-05 |
| 6     | 1.197537 | 1.75E-05 | 1.197547 | 3.34E-05 | 1.197542 | 1.197502 | 4.59E-05 |
| 8     | 1.596236 | 1.75E-05 | 1.596245 | 3.57E-05 | 1.596241 | 1.596191 | 4.64E-05 |
| 10    | 1.994962 | 1.70E-05 | 1.994972 | 3.66E-05 | 1.994967 | 1.994907 | 4.91E-05 |

### Table 7. 1 kN force transducer measurement results

| Force | UME 1 | UME 2 | UME AVE | SASO |
|-------|-------|-------|---------|------|
| kN    | Mean Value | Deviation | Mean Value | Deviation | Mean Value | Mean Value | Deviation |
| F     | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(b_{rp}\) | \(X_{ave}\) | \(X_{ave}\) | \(b_{rp}\) |
| 0     | 0.000000 | -     | 0.000000 | -     | 0.000000 | 0.000000 | -     |
| 0.4   | 0.797275 | 1.38E-05 | 0.797271 | 8.78E-06 | 0.797273 | 0.797250 | 1.88E-05 |
| 0.6   | 1.195915 | 1.00E-05 | 1.195911 | 5.85E-06 | 1.195913 | 1.195877 | 2.42E-05 |
| 0.8   | 1.594547 | 8.78E-06 | 1.594544 | 3.14E-06 | 1.594546 | 1.594501 | 3.76E-05 |
| 1.0   | 1.993169 | 8.03E-06 | 1.993167 | 3.01E-06 | 1.993168 | 1.993120 | 5.27E-05 |
Readings Corrections due to using different indicators at UME and SASO

For these measurements, the indicators used in UME (HBM, DMP 40 S6, SN: 964720034) and in SASO (HBM, DMP 40, SN: 172820006). Instead of transferring the DMP 40, BN 100 calibrator belonging to UME transferred to SASO to check both DMP 40s belonging to SASO and UME. The difference of average measurement results on UME and SASO indicators are given in table 8. In the calculations, DMP 40 indicator deviation values according to BN 100 of pilot laboratory were taken into consideration.

Table 8. The average data is taken SASO indicator by using BN 100 calibrator

| BN 100 Setting mV/V | SASO DMP40 mV/V | Difference mV/V |
|---------------------|-----------------|-----------------|
| +0.000 000          | 0.000000        | 0.000000        |
| +0.400 000          | 0.399998        | 0.000002        |
| +0.800 000          | 0.799994        | 0.000006        |
| +1,200 000          | 1,199995        | 0.000005        |
| +1,600 000          | 1,599993        | 0.000007        |
| +2,000 000          | 1,999992        | 0.000008        |

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 9.

Table 9. The corrected average data of SASO for 100 kN, 10 kN and 1 kN force transducers

| Force kN | SASO average results SASO mV/V | SASO corrected values SASOcor mV/V |
|----------|---------------------------------|-----------------------------------|
| 0.4      | 0.797250                        | 0.797256                          |
| 0.6      | 1.195877                        | 1.195882                          |
| 0.8      | 1.594501                        | 1.594508                          |
| 1.0      | 1.993120                        | 1.993128                          |
| 4        | 0.798323                        | 0.798329                          |
| 6        | 1.197502                        | 1.197507                          |
| 8        | 1.596191                        | 1.596198                          |
| 10       | 1.994907                        | 1.994915                          |
| 40       | 0.798907                        | 0.798913                          |
| 60       | 1.198377                        | 1.198382                          |
| 80       | 1.597869                        | 1.597876                          |
| 100      | 1.997392                        | 1.997400                          |
Table 10. Calculated relative uncertainty contributions of 100 kN force transducer

| F (kN) | $w^2(X)$ | $w^2(F_{fsnm})$ | $W(K_{TS})$ | $w^2(D)$ | $W_{rv}$ | $w^2(d_{fcm})$ | $|\Delta d|$ | $W_{CMC}$ | $W_{CMC}$ | $%$ |
|--------|----------|-----------------|-------------|----------|---------|----------------|----------|----------|----------|-----|
| 40     | 4.78E-11 | 1.00E-10        | 2.43E-05    | 1.47E-10 | 3.44E-05| 5.26E-11       | 1.58E-05| 6.27E-05|          | 0.006|
| 60     | 3.48E-11 | 1.00E-10        | 2.32E-05    | 8.92E-11 | 2.99E-05| 5.66E-11       | 2.54E-05| 5.89E-05|          | 0.006|
| 80     | 4.80E-11 | 1.00E-10        | 2.43E-05    | 8.78E-12 | 2.50E-05| 6.31E-11       | 2.45E-05| 5.50E-05|          | 0.006|
| 100    | 4.86E-11 | 1.00E-10        | 2.44E-05    | 1.16E-10 | 3.25E-05| 5.69E-11       | 2.04E-05| 6.12E-05|          | 0.006|

Table 11. Calculated relative uncertainty contributions of 10 kN force transducer

| F (kN) | $w^2(X)$ | $w^2(F_{fsnm})$ | $W(K_{TS})$ | $w^2(D)$ | $W_{rv}$ | $w^2(d_{fcm})$ | $|\Delta d|$ | $W_{CMC}$ | $W_{CMC}$ | $%$ |
|--------|----------|-----------------|-------------|----------|---------|----------------|----------|----------|----------|-----|
| 4      | 1.63E-12 | 1.00E-10        | 2.02E-05    | 5.66E-11 | 2.52E-05| 5.49E-11       | 2.05E-05| 5.81E-05|          | 0.006|
| 6      | 1.11E-11 | 1.00E-10        | 2.11E-05    | 2.51E-11 | 2.33E-05| 6.57E-11       | 2.89E-05| 5.73E-05|          | 0.006|
| 8      | 9.95E-12 | 1.00E-10        | 2.10E-05    | 9.68E-12 | 2.19E-05| 7.35E-11       | 2.64E-05| 5.67E-05|          | 0.006|
| 10     | 9.92E-12 | 1.00E-10        | 2.10E-05    | 8.04E-12 | 2.17E-05| 8.37E-11       | 2.60E-05| 5.73E-05|          | 0.006|

Table 12. Calculated relative uncertainty contributions of 1 kN force transducer

| F (kN) | $w^2(X)$ | $w^2(F_{fsnm})$ | $W(K_{TS})$ | $w^2(D)$ | $W_{rv}$ | $w^2(d_{fcm})$ | $|\Delta d|$ | $W_{CMC}$ | $W_{CMC}$ | $%$ |
|--------|----------|-----------------|-------------|----------|---------|----------------|----------|----------|----------|-----|
| 0.4    | 5.88E-12 | 1.00E-10        | 2.06E-05    | 6.06E-12 | 2.12E-05| 1.03E-11       | 2.11E-05| 4.81E-05|          | 0.005|
| 0.6    | 3.57E-12 | 1.00E-10        | 2.04E-05    | 4.11E-12 | 2.08E-05| 1.87E-11       | 2.60E-05| 4.85E-05|          | 0.005|
| 0.8    | 3.56E-12 | 1.00E-10        | 2.04E-05    | 8.85E-13 | 2.04E-05| 4.92E-11       | 2.39E-05| 5.08E-05|          | 0.005|
| 1.0    | 2.43E-12 | 1.00E-10        | 2.02E-05    | 1.64E-13 | 2.03E-05| 1.08E-10       | 2.01E-05| 5.51E-05|          | 0.006|
Fig. 7. The graph of relative deviation of 100 kN force transducer

Fig. 8. The graph of relative deviation of 10 kN force transducer

Fig. 9. The graph of relative deviation of 1 kN force transducer
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.

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

| Force | UME | $\pm U_{cml}$ | Corrected reading | $\pm U_{cml}$ | $E_n$ |
|-------|-----|----------------|------------------|---------------|------|
| kN    |     | Average reading |                  |               |      |
| 0.4   | 0.797273 | 0.002 | 0.797256 | 0.005 | 0.4 |
| 0.6   | 1.195913 | 0.002 | 1.195882 | 0.005 | 0.5 |
| 0.8   | 1.594546 | 0.002 | 1.594508 | 0.005 | 0.4 |
| 1     | 1.993168 | 0.002 | 1.993128 | 0.005 | 0.4 |
| 4     | 0.798345 | 0.002 | 0.798329 | 0.006 | 0.3 |
| 6     | 1.197542 | 0.002 | 1.197507 | 0.006 | 0.5 |
| 8     | 1.596241 | 0.002 | 1.596198 | 0.006 | 0.4 |
| 10    | 1.994967 | 0.002 | 1.994915 | 0.006 | 0.4 |
| 40    | 0.798926 | 0.002 | 0.798913 | 0.006 | 0.2 |
| 60    | 1.198412 | 0.002 | 1.198382 | 0.006 | 0.4 |
| 80    | 1.597915 | 0.002 | 1.597876 | 0.006 | 0.4 |
| 100   | 1.997441 | 0.002 | 1.997400 | 0.006 | 0.3 |

As it seen the $E_n$ number for this comparison measurements given in table 13 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 three range in 1 kN, 10 kN and 100 kN was compared with SASO NMCC force standard machines.

This uncertainty value of SASO NMCC is approved by the En values given in Table 13 as $|\text{En}| \leq 1$ and results is called as “successful”.

12. References

[1] CIPM MRA-D-05, Measurement comparisons in the CIPM MRA, 2016 (available on the BIPM website: http://www.bipm.org/en/cipm-mra/cipm-mra-documents/)

[2] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)

[3] EA Publication EA-4/02, Expression of the Uncertainty of Measurement in Calibration

[4] ISO / IEC 17043 “Conformity assessment — General requirements for proficiency testing”, International Standardization Organization”, 2010

[5] Calibration Guide EURAMET/cg-04/v.02 (03/2011)-Uncertainty of Force Measurements

[6] Tegtmeier, F., Kumme, R., Seidel, M., Improvement of the realization of forces between 2 MN and 5 MN at PTB, XIX IMEKO World Congress, Fundamental and Applied Metrology, September 6-11, 2009, Lisbon, Portugal

[7] Dizdar, H., Aydemir, B., Vatan, C., Kuvvet Ölçümlerinde Belirsizlik, 2015, EURAMET cg-4, 2. Baskı (03/2011) çeviri, Şubat 2015, TÜBİTAK UME

[8] Aydemir, B., Fank, S., Vatan, C., Interlaboratory comparisons performed in Turkey: Force calibration of static material testing, 2012, XX IMEKO World Congress, September 9-14, 2012, Busan, Republic of Korea, S.1-4