

IMEKO 2010 TC3, TC5 and TC22 Conferences  
Metrology in Modern Context  
November 22–25, 2010, Pattaya, Chonburi, Thailand

## INTERLABORATORY COMPARISON OF FORCE MEASUREMENT IN THAILAND

*Kittipong Chaemthet*<sup>1</sup>, *Chanchai Amornsakun*<sup>2</sup>, *Sumet Heamawatanachai*<sup>3</sup>

<sup>1</sup>National Institute of Metrology (Thailand), Pathumthani, Thailand, [kittipong@nimt.or.th](mailto:kittipong@nimt.or.th)

<sup>2</sup>National Institute of Metrology (Thailand), Pathumthani, Thailand, [chanchai@nimt.or.th](mailto:chanchai@nimt.or.th)

<sup>3</sup>National Institute of Metrology (Thailand), Pathumthani, Thailand, [sumet@nimt.or.th](mailto:sumet@nimt.or.th)

**Abstract** – This paper presents the force interlaboratory comparison between the National Institute of Metrology Thailand (NIMT), and six participating laboratories in Thailand. The circulated artefacts were tested in both compression and tension of two rated ranges (50 kN and 100 kN). The star formation was used in this comparison project. The artefacts were tested at NIMT before and after sending to each participant, by using a 100 kN deadweight machine as a reference standard.

**Keywords:** force comparator machine, force transducer, interlaboratory comparison

### 1. INTRODUCTION

The 100 kN deadweight force standard machine (DWM), as seen in Fig. 1, has been installed at the National Institute of Metrology, Thailand (NIMT) in 2005. A bilateral comparison with the National Metrology Institute of Japan (NMIJ) has been successfully made in 2007 [1]. This 100 kN DWM has been used to transfer the Thai National force standard to calibration laboratories through calibrating of their force measuring devices.

Typically, these laboratories used the calibrated devices to transfer forces value to industries by using force comparator machine. The quality of the calibration results from this technique depended on many factors such as skill of the laboratory person and alignment of the system.

Another group of calibration laboratories used lever force amplification machines which the pre-amplified forces were generated from deadweight. This type of machine has good long term stability. However, lacking of maintenance and bad alignment could cause a large error in generating forces.

The objectives of this intercomparison project were to verify the performance of the participating laboratories and to give them suggestions in correction of their systems if required.

There were six laboratories participated in this comparison project. Two of them used lever force amplification machines and the others used force comparator machines. The star formation was performed for this comparison where NIMT was the pilot laboratory.



Figure 1. 100 kN NIMT national deadweight force standard machine.

### 2. PROTOCOL

#### 2.1. Equipment

The reference measuring equipments, as seen in table 1 and figure 2, were provided by NIMT.

The temperature sensitivity coefficient of transducers were given by the manufacture as  $\pm 0.001\% \text{ } ^\circ\text{C}^{-1}$  for C4 model and  $\pm 0.005\% \text{ } ^\circ\text{C}^{-1}$  for U2A model

Table 1. List of equipment.

Equipment	Description	S/N
Indicator	HBM model DK38.D20	28533
Transducer	100 kN, HBM-C4	C57771
	100 kN, HBM-U2A	D11794
	50 kN, HBM-C4	G84927
	50 kN, HBM-U2A	D16017
Adapter	Thrust piece for C4	provide by NIMT
	Tension adapter for U2A	



Figure 2(a). Digital force indicator

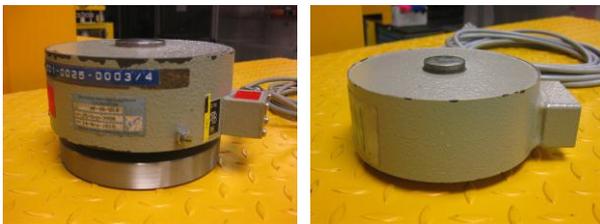


Figure 2(b). 100 kN, HBM-C4    Figure 2(c). 50 kN, HBM-C4



Figure 2(d). 100 kN, HBM-U2A    Figure 2(e). 50 kN, HBM-U2A

**2.2. Timetable**

In each branch of comparison (NIMT - Lab xA - NIMT), the reference equipments (artefacts) were initially measured at NIMT. Then they were sent to each laboratory for measurement (each laboratory had a week to finish their measurement). After that, the artefact will be sent back to NIMT for post measurement and to begin the next branch.

**2.3. Measurement instructions**

The measurement procedure in this comparison project was based on ISO 376:2004(e) [2]. The measurement protocol is shown in Figure 3.

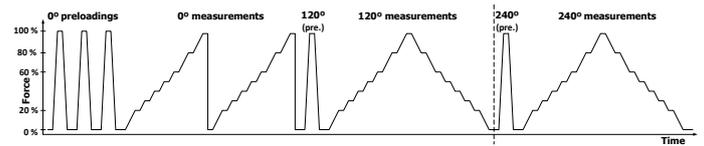


Figure 3. Calibration protocol for the measurement

**3. RESULTS**

**3.1. Stability of artefact**

Figure 4 to 7 show the stability of the artefacts which were measured at NIMT from every branches of comparison. The results from 20% to 100% of range were shown. The 100 kN DWM was used to generate the reference forces.

From figure 4 to 7, in compression mode, the stability of the artefact with range of 50 kN has relative deviation of  $\pm 250$  ppm. For the 100 kN range artefact, the relative deviation is  $\pm 50$  ppm. In tension mode, the stability of the 50 kN range artefact has relative deviation of  $\pm 160$  ppm. And for the 100 kN range artefact, the relative deviation is  $\pm 80$  ppm.

Note that, each laboratory had one week to finish the measurement. For each branch, the total time between the measurement at NIMT before and after sending to each participant was about 2 weeks. As seen in figure 4 to 7, the artefacts were measured at NIMT at the week of 0, 2, 4, 6, 8 and 10 respectively. To compare with each laboratory, the results of NIMT at the beginning of each branch will be used as reference. For example, the results from NIMT at week# 2 will be used as reference to compare with the results from laboratory at week# 3.

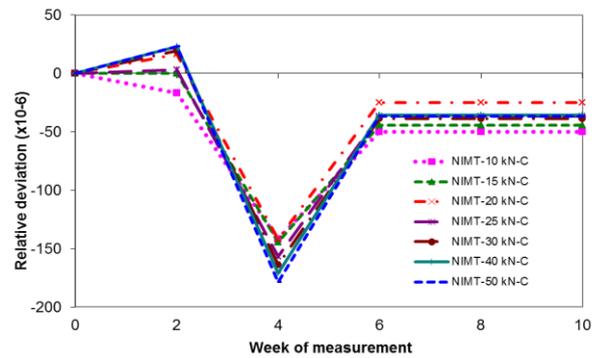


Figure 4. Stability of 50 kN HBM model C4

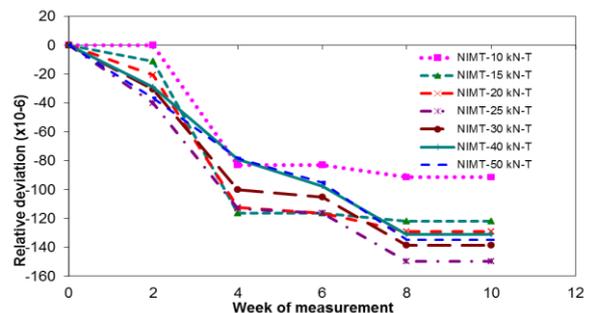


Figure 5. Stability of 50 kN HBM model U2A

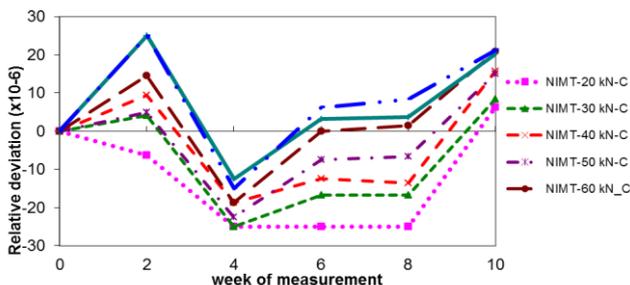


Figure 6. Stability of 100 kN HBM model C4

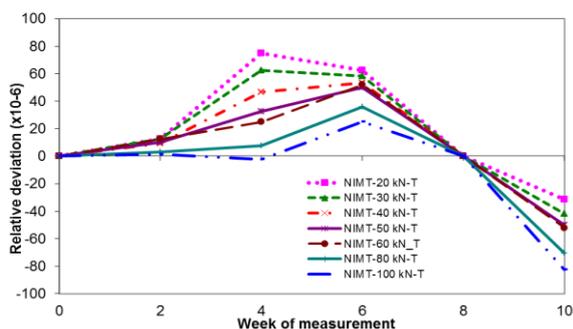


Figure 7. Stability of 100 kN HBM model U2A

3.2. 50 kN range Calibration results

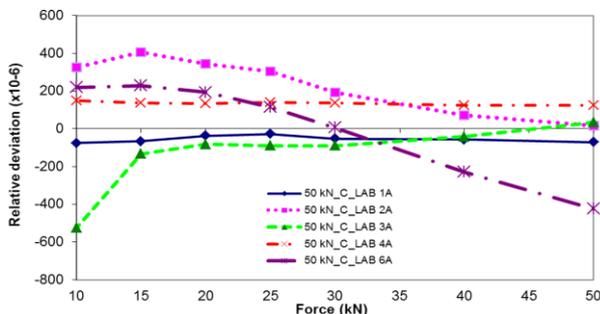


Figure 8. Rel.error of 50 kN HBM model C4

Figure 8 shows the comparison results between NIMT and 5 participants in compressive mode at 50 kN rated capacity. The relative deviation is about  $\pm 500$  ppm.

For tension mode as seen in figure 9 and 10, the results were separated and plotted into 2 groups categorized by type of machine. The first group as shown in figure 9, the measurements were made using force comparator machines. The relative deviations from this group were about  $\pm 400$  ppm. The second group used lever amplification machines as seen in figure 10. The relative deviations were very large (-25000 to -40000 ppm) at low force (20%) and smaller (-12000 to -15000 ppm) at high force (100%). There are many factors that can cause of the large relative deviation such as the bad alignment, lacking of maintenance and the effect from difference adaptors.

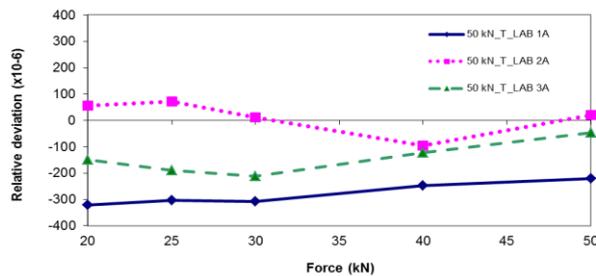


Figure 9. Rel.error of 50 kN HBM model U2A

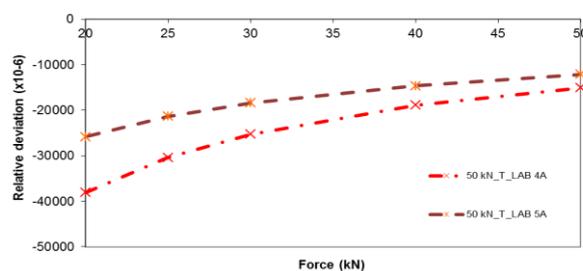


Figure 10. Rel.error of 50 kN HBM model U2A

3.3. 100 kN range Calibration results

Figure 11 shows the comparison between NIMT and 4 participants in compressive mode at 100 kN rated capacity, the relative deviations were about  $\pm 600$  ppm.

Figure 12 shows comparison results in tensile mode. Universal comparator machines were used in this experiment. The relative deviation is about  $\pm 800$  ppm. In case of lever amplification machine as seen in figure 13, the relative deviations were large (-50000 ppm) at low force, and were smaller (-12000 to -15000 ppm) at high force. This is similar to the tensile mode test at 50 kN as seen in figure 10.

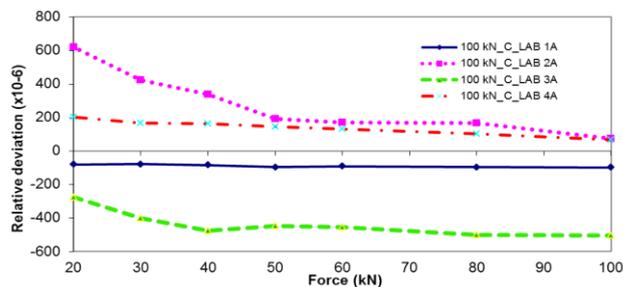


Figure 11. Rel.error of 100 kN HBM model C4

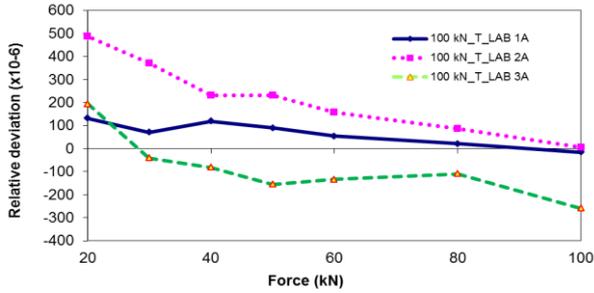


Figure 12. Rel.error of 100 kN HBM model U2A

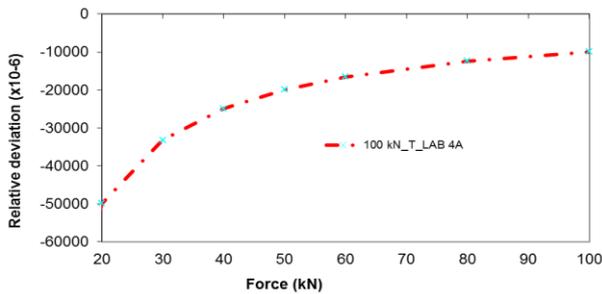


Figure 13. Rel.error of 100 kN HBM model U2A

### 3.4. Calculation of $E_n$ value

Averages of readings, repeatability, reproducibility, resolution, temperature fluctuation, sensitivity drift between the initial and final were taken into account when estimating the uncertainty of the comparison measurements.  $E_n$  numbers were calculated to evaluate the comparison results according to ISO/IEC Guide 43-1.[3] as:

$$E_n = \frac{X_{lab} - X_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad (1)$$

where  $X_{lab}$  is the value obtained at a given laboratory  
 $X_{ref}$  is the value of NIMT  
 $U_{lab}$  is the uncertainty of participant's result  
 $U_{ref}$  is the uncertainty of reference value (NIMT)

An  $E_n$  value of greater than 1 indicates that the difference between the two laboratories may be significant, as it cannot be explained by the combination of the uncertainties.

Table 2 to 5 show  $E_n$  values from the comparison results of all participants. The  $U_{exp}$  indicates the relative expanded uncertainty in ppm, which was calculated from the combined uncertainty of  $U_{lab}$  and  $U_{ref}$ .

Table 2.  $U_{Exp}$  and  $E_n$  number of 50 kN compression and Tension (LAB 1A to LAB 3A)

Force step kN/mode	LAB 1A		LAB 2A		LAB 3A	
	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$
10/C	445.3	0.17	520.6	0.62	841.7	0.62
15/C	451.7	0.15	504.7	0.80	832.2	0.16
20/C	423.3	0.09	481.2	0.71	762.1	0.11
25/C	393.2	0.07	465.4	0.65	713.9	0.13
30/C	373.6	0.14	436.8	0.44	682.7	0.13
40/C	341.5	0.17	417.1	0.17	625.7	0.07
50/C	332.9	0.21	430.2	0.04	595.3	0.06
10/T	364.4	0.56	1486.4	0.11	2258.7	0.40
15/T	410.9	0.55	1377.8	0.06	1568.9	0.45
20/T	711.4	0.45	1265.2	0.04	1314.2	0.11
25/T	622.3	0.49	1186.3	0.06	989.7	0.19
30/T	536.8	0.57	1119.7	0.01	827.1	0.26
40/T	401.4	0.61	1034.6	0.09	665.8	0.19
50/T	341.7	0.65	1006.7	0.02	510.2	0.09

Table 3.  $U_{Exp}$  and  $E_n$  number of 50 kN compression and Tension (LAB4A to LAB 6A)

Force step kN/mode	LAB 4A		LAB 5A		LAB 6A	
	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$
10/C	593.6	0.25	N/A	N/A	54717.4	0.00
15/C	552.3	0.25	N/A	N/A	39104.4	0.01
20/C	527.2	0.25	N/A	N/A	3145.7	0.06
25/C	501.1	0.28	N/A	N/A	22683.3	0.01
30/C	475.0	0.29	N/A	N/A	29423.1	0.00
40/C	454.2	0.27	N/A	N/A	28930.4	0.01
50/C	442.4	0.28	N/A	N/A	7583.1	0.06
10/T	1384.1	55.28	66730.3	0.75	53202.4	37.64
15/T	1296.0	39.28	4559.9	7.48	40982.4	48.89
20/T	1187.2	32.05	41919.6	0.62	3164.6	632.50
25/T	1128.9	26.92	24486.8	0.87	23327.9	85.75
30/T	1061.1	23.82	66885.6	0.27	29704.9	67.32
40/T	1026.9	18.40	35853.6	0.41	29369.4	68.07
50/T	1010.4	14.90	6154.2	1.97	7749.9	257.98

From table 2 and 5, three laboratories (LAB 1A, LAB 2A and LAB 3A) have good performance in both compressive and tensile modes. Force comparator machines were used as their force standard. The expanded uncertainties ( $U_{Exp}$ ) were less than 712 ppm for LAB 1A,

1490 ppm for LAB 2A and 2600 ppm for LAB 3A. The  $E_n$  values of the results from these laboratories were less than 1 which were in the acceptable range. The results also indicated that the uncertainties in tensile mode were more than in compressive mode due to the effect of alignment of the adapter.

LAB 4A used lever amplification machine as a force standard. The expanded uncertainties were less than 600 ppm for the compressive mode.  $E_n$  values were in the acceptable range. However, the  $E_n$  values of tensile mode were larger than 1, indicated that the machine had offset errors in tensile mode. This machine required some maintenance or recalibration.

LAB 5A used lever amplification machine as a force standard. Although most of the  $E_n$  values were less than 1, but the expanded uncertainties were very large (60000 ppm). This could be from the mechanical problem of the machine, the skill of person and bad alignment.

LAB 6A used force comparator machine as a force standard. The expanded uncertainties were very large (50000 ppm). This could be the result from bad alignment, skill of person, mechanical problem etc. Further investigation required in order to fix these problems.

Table 4. Expanded uncertainty ( $U_{Exp}$ ) and  $E_n$  number ( $E_n$ ) of 100 kN comparison and Tension (LAB 1A to LAB 3A)

Force step kN/mode	LAB 1A		LAB 2A		LAB 3A	
	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$
20/C	478.6	0.17	724.2	0.85	2557.8	0.11
30/C	421.0	0.19	624.7	0.68	2131.6	0.19
40/C	386.4	0.22	508.9	0.66	1949.1	0.24
50/C	353.8	0.28	498.6	0.39	1645.3	0.27
60/C	333.7	0.27	484.8	0.35	1292.0	0.35
80/C	312.4	0.31	438.5	0.38	671.2	0.74
100/C	303.6	0.33	413.9	0.18	409.2	1.23
20/T	574.2	0.23	739.4	0.66	2593.8	0.07
30/T	478.6	0.15	584.7	0.63	2378.6	0.02
40/T	433.9	0.27	574.6	0.40	2101.7	0.04
50/T	384.5	0.23	762.6	0.30	1778.9	0.09
60/T	368.6	0.15	515.5	0.31	1553.2	0.09
80/T	318.6	0.06	480.0	0.18	1144.2	0.10
100/T	307.5	0.05	459.7	0.01	1021.7	0.25

Table 5. Expanded uncertainty ( $U_{Exp}$ ) and  $E_n$  number ( $E_n$ ) of 100 kN comparison and Tension (LAB 4A to LAB 6A)

Force step kN/mode	LAB 4A		LAB 5A		LAB 6A	
	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$	$U_{Exp}$ (ppm)	$E_n$
20/C	538.7	0.38	N/A	N/A	54717.4	0.08
30/C	507.3	0.33	N/A	N/A	39104.4	0.07
40/C	480.0	0.34	N/A	N/A	3145.7	0.12
50/C	455.3	0.32	N/A	N/A	22683.3	0.10
60/C	438.7	0.30	N/A	N/A	29423.1	0.09
80/C	416.9	0.25	N/A	N/A	28930.4	0.15
100/C	410.2	0.16	N/A	N/A	7583.1	11.77
20/T	1193.8	41.77	N/A	N/A	54805.5	36.54
30/T	1177.1	28.20	N/A	N/A	39178.1	51.11
40/T	1137.6	21.89	N/A	N/A	3269.1	612.44
50/T	1117.5	17.82	N/A	N/A	22830.7	87.68
60/T	1103.9	15.00	N/A	N/A	29392.4	68.10
80/T	1074.8	11.53	N/A	N/A	28980.8	69.05
100/T	1051.1	9.44	N/A	N/A	7654.8	248.33

#### 4. CONCLUSIONS

In this comparison, star formation method was used because the drift of the artefacts can be compensated and to ensure that the artefacts were in good condition before sending to each participant.

The comparison results show that, all the participants have good performance at measurement in the compressive mode. The relative deviations at more than 50% of range were within  $\pm 500$  ppm. However, in tensile mode, the relative deviations from some laboratories were very large ( $> 10000$  ppm). These laboratories require further investigation in order to solve the problem.

From EA-10/04(EAL-G22) [4], the expanded uncertainty for the comparator machine should be between 500 to 5000 ppm. And the uncertainty of lever amplification machine should be between 100 to 500 ppm. From the comparison results, LAB 1A, LAB 2A and LAB 3A had good performance in force measure for both compressive and tensile mode. For LAB 4A and LAB 5A, which used the lever amplification machine, still need to solve the problem on alignment and the machine required some maintenance. For LAB 6A, the uncertainties of measurements were very large indicating that the measurement system need to be corrected.

This interlaboratory comparison project has an advantage for NIMT to know the performance of force laboratories in Thailand. It can also be used as a guide line to for NIMT to improve the Thai metrology system in the field of force measurement.

## REFERENCES

- [1] Kittipong Chaemthet, Chanchai Amornsakun, Noppadol Sumyong, Veera Tulasombut, Toshiyuk Hayashi, Kazunaga Ueda, “A Bilateral Comparison of Force Standard between NIMT and NMIJ”, *Proc. 6th Asia-Pacific Symposium on Measurement of Mass, Force, Torque and Density (APMF 2007)*, Sydney, Oct. 24-26, 2007, pp.193-198.
- [2] ISO 376, “Metallic material – Calibration of force-proving instruments used for the verification of uniaxial testing machines”:2004
- [3] ISO/IEC Guide 43-1, “Proficiency testing by interlaboratory comparisons — Part 1: Development and operation of proficiency testing schemes”, p. 12, 1997.
- [4] EA-10/04(EAL-G22):1996, “Uncertainty of Calibration Results in Force Measurement” Edition 1, August 1966