IMEKO 20th TC3, 3rd TC16 and 1st TC22 International Conference
Cultivating metrological knowledge
27th to 30th November, 2007. Merida, Mexico.

Force standards comparison at 1 kN and 50 kN among national laboratories from EUROMET and SIM

C. Villarroel-Poblete [1], J. C. Torres-Guzman [2], P. Averlant [3], A. Knott [4], R. Kumme [5], J. A. Robles-Carbonell [6], D. Ramirez-Ahedo [2], L. R. Giobergia [7]

[1] Instituto de Investigaciones y Control (IDIC), Chile.
[2] Centro Nacional de Metrologia, Mexico.
[3] Laboratoire national de métrologie et d'essais, LNE. France.
[4] National Physical Laboratory, UK.
[5] Physikalisch-Technische Bundesanstalt (PTB), Germany.
[6] Centro Español de Metrología (CEM). Spain.
[7] Instituto Nacional de Tecnologia Industrial (INTI), Argentina.

Abstract

A force comparison was carried out among various laboratories from Euromet and SIM, in order to estimate the level of agreement for the realization of the quantity and the uncertainty associated to its measurement. The comparison was carried out in two ranges one at 1 kN and the other at 50 kN. In order to achieve best accuracy of the force transducers the measurement range started at 40% of the maximum transducer range. The results obtained, the deviations graphs that include the uncertainty for each laboratory are presented in this document.

Keywords: Force, international comparison, SIM, Euromet.

1. Introduction

A force comparison in two ranges (1 kN and 50 kN) was carried out in order to estimate the level of agreement for the realization of the quantity, and the uncertainty associated to its measurement. This constitutes the first force comparison between the two metrological regions involving more than one laboratory per region.

1.1 Scope of Work

The ISO publication "International Vocabulary of Basic and General Terms of Metrology" (VIM), and the International System of Units, SI, were used for the comparison and for the writing of this document. The recommendations in the Guide to the Expression of Uncertainty in Measurement and the Guidelines for key comparison carried out by Consultative Committees were followed [1, 2, 3, 4].

1.2 Program Objectives

To compare force measurement among the participant national laboratories in the ranges of 1 kN and 50 kN.

2. Comparison

2.1 Comparison Standards

In order to achieve best accuracy of the comparison force transducers used, the measurement ranges were chosen starting at 40% of the maximum transducer range. Details follow in Table 1.

Table 1
Comparison general information

Instrument	Make	Comparison Sub Ranges	Force Steps
Digital Amplifier (DMP40)	HBM	-	-
Force Transducer up to 1 kN	HBM	0.4 kN to 1 kN	0.4 kN, 0.6 kN, 0.8 kN and 1 kN
Force Transducer up to 50 kN	HBM	20 kN to 50 kN	20 kN, 30 kN, 40 kN and 50 kN

Each laboratory used its own digital amplifier (DMP40).

2.2 Comparison Round

The complete measurements exercise for the comparison program was performed between June 2003 and June 2004.

2.3 General Guidelines and Procedure

The most relevant aspects of the comparison ***General Guidelines*** [5] and the measurements ***General Procedure*** [6] are included in Tables 1 and 2.

Table 2
Comparison procedure

Readings positions:	0°, 90°, 180°, 270° and 360°
Readings cycles:	3 cycles in 90°, one cycle in all other positions with a down load reading at 360°
Force application time:	90 s
Preloads application time:	90 s with 90 s resting time between preloads
Number of preloads (at maximum force):	3 at 0° (including 1 step preload), 1 at all other positions
Temperature during measurements:	22°C ± 0,5 K

The forces were applied in such a way that their application strictly increases in the upward direction up to the measured force point. The readings were be obtained in mV/V.

3. Laboratories' Standards

All participating laboratories used their national standard for the compared range. All standards were dead weight force machines (DWFM) except IDIC (Chile) who used a hydraulic force comparator machine.

4. Results

To calculate the deviations and the uncertainties from the measured data, the following considerations were made:

- The laboratories deviations were calculated respect to the mean of the values obtained by the participating primary laboratories (CENAM, CEM, LNE, NPL and PTB), namely reference deviation values.
- The uncertainties calculated were based mainly, on four contributing elements; the standard used by the laboratory (according to the values reported in the BIPM data base), repeatability of measurements in 0°, reproducibility of the results, and resolution of the comparison standard (force transducer and digital amplifier).
- As the measurements were taken in mV/V, the results are presented relative to the corresponding nominal force value applied.

The results of the measurements made are here presented for each sub range. The results are shown in figures 1 to 10, five figures for each sub range. In all figures 2 graphs are presented, one with all participating laboratories included and another one showing the results from the primary laboratories (to obtain better resolution of the graphs).

4.1 Force Transducer up to 1 kN

Figures 1 to 5 show the deviations of the laboratories for the 1 kN force transducer. In figure 1, the deviations for each laboratory are shown. Figures 2 to 5 present the deviations and corresponding uncertainties for each laboratory at each compared force target point.

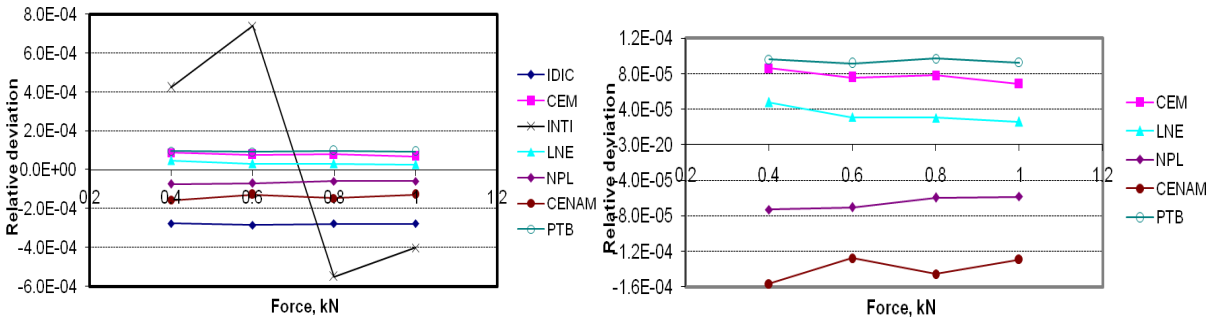

Figure 1. Relative deviations among the participating laboratories for the subrange 0.4 kN to 1 kN. a) All participant laboratories b) Primary laboratories.

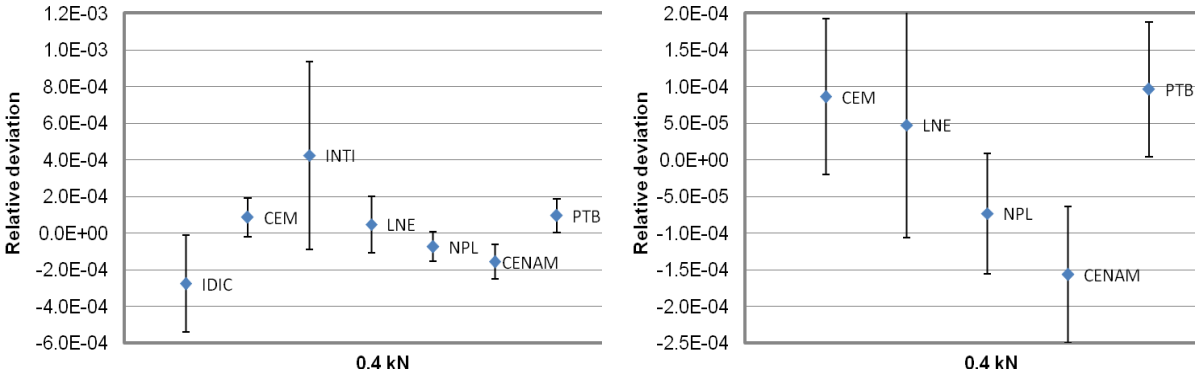

Figure 2. Relative deviations and uncertainties for 0.4 kN.
a) All laboratories b) Primary laboratories.

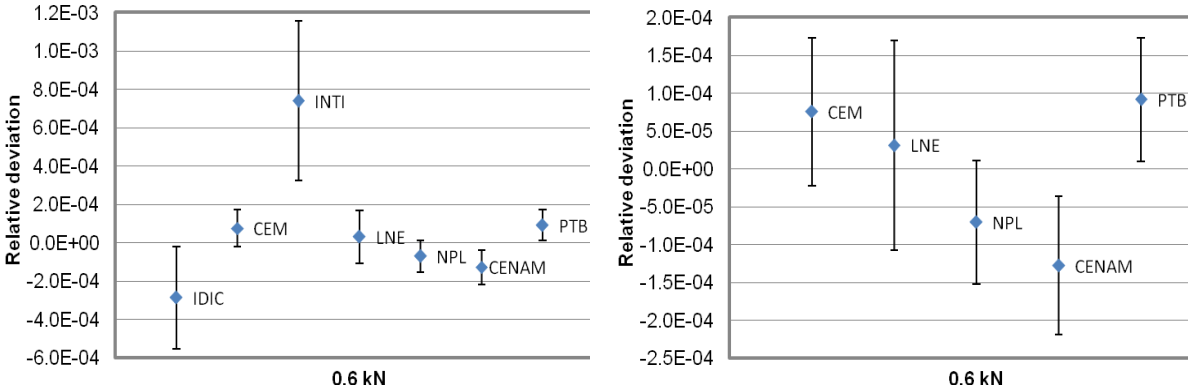

Figure 3. Relative deviations and uncertainties for 0.6 kN.
a) All laboratories b) Primary laboratories.

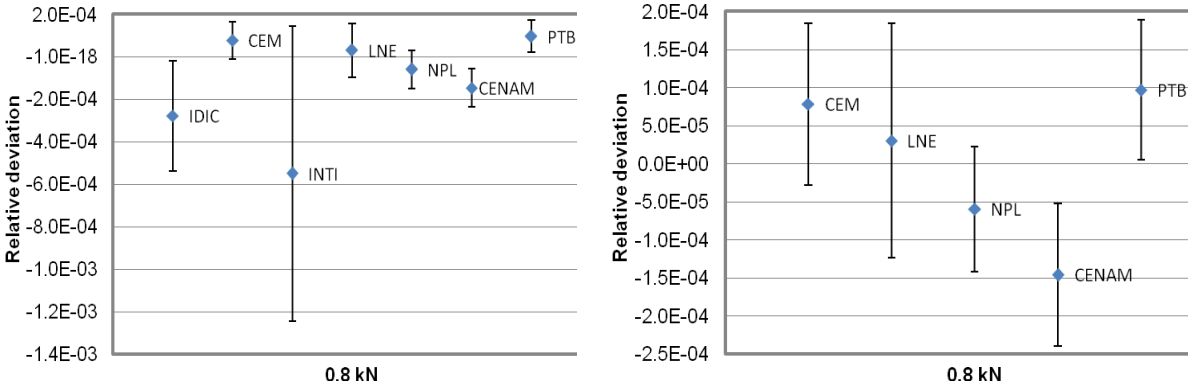

Figure 4. Relative deviations and uncertainties for 0.8 kN.
a) All laboratories b) Primary laboratories

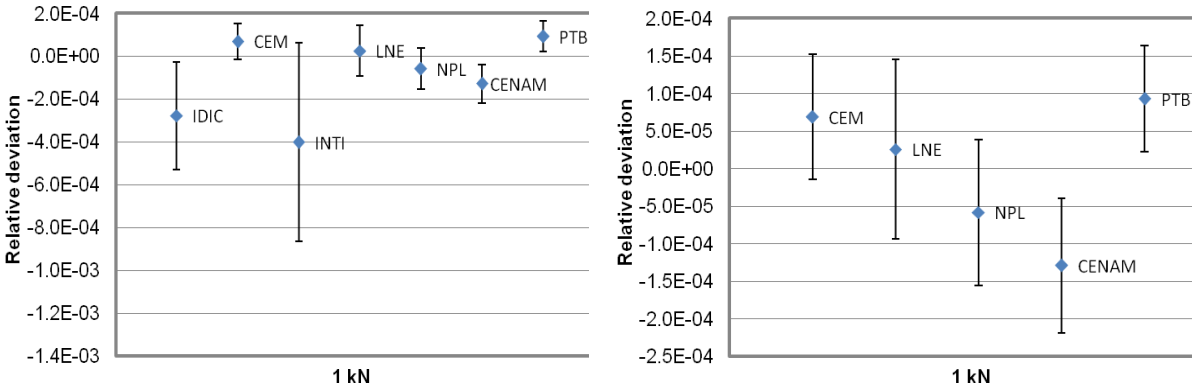

Figure 5. Relative deviations and uncertainties for 1 kN.
a) All laboratories b) Primary laboratories.

4.2 Force Transducer up to 50 kN

For the range up to 50 kN the relative deviations were bigger and the difference in the value of uncertainty assigned to the measured forces by the laboratories were much greater than that found for the range of 1kN, making the difference with the reference values greater. It seems that a time dependency could exist due to some deviation of the load cell. The study made to measure the drift effect is not adequate since the measurements were made with an uncertainty too big to notice the differences. Also, the load cell used as transfer standard presented high sensitivity to ground connection, requiring isolating the load cell with metal foil. For these reasons, the results found for this range were though not to be adequate for the purposes of this comparison. Figure 6 shows the measurements found at 50 kN.

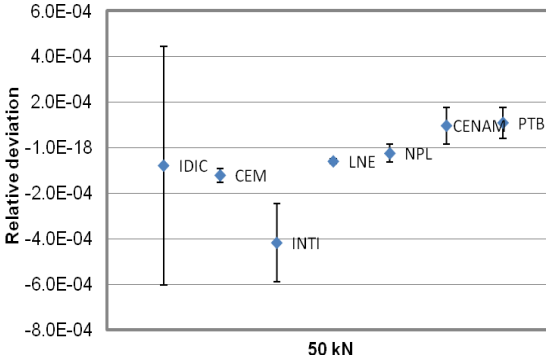

Figure 6. Relative deviations and uncertainties at 50 kN for all participating laboratories.

5. Discussion

In order to compare in a better way the measurement results, a normalized error graph can be used. The equation used here (equation 1) takes into account the considerations presented in the previous section 4. As readings were made in mV/V, the calculated relative deviations are considered instead of using a force lecture.

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

Where,

e_n - normalized error
e_{lab} - laboratory's estimated relative deviation
e_{ref} - mean value reference deviation calculated from the deviations of the primary laboratories = (e_{CENAM} + e_{CEM} + e_{LNE} + e_{NPL} + e_{PTB}) / 5
U_{lab} - laboratory's expanded uncertainty
U_{ref} - Combined expanded uncertainty of the primary participating laboratories (according to equation 2).

$$U_{ref} = \frac{\sqrt{U_{CENAM}^2 + U_{CEM}^2 + U_{LNE}^2 + U_{NPL}^2 + U_{PTB}^2}}{\sqrt{5}} \quad (2)$$

The normalized error equation (2) is used to obtain a new set of graphs for the two force sub ranges compared. It is important to point out that the values should be equal or below 1.0 if equivalence of measurements is to be achieved, as discussed in [7, 8 and 9]. In figures 7 and 8, two graphs are shown; the first one with the results of all participating laboratories and the other with the primary laboratories results.

5.1 Force Transducer up to 1 kN

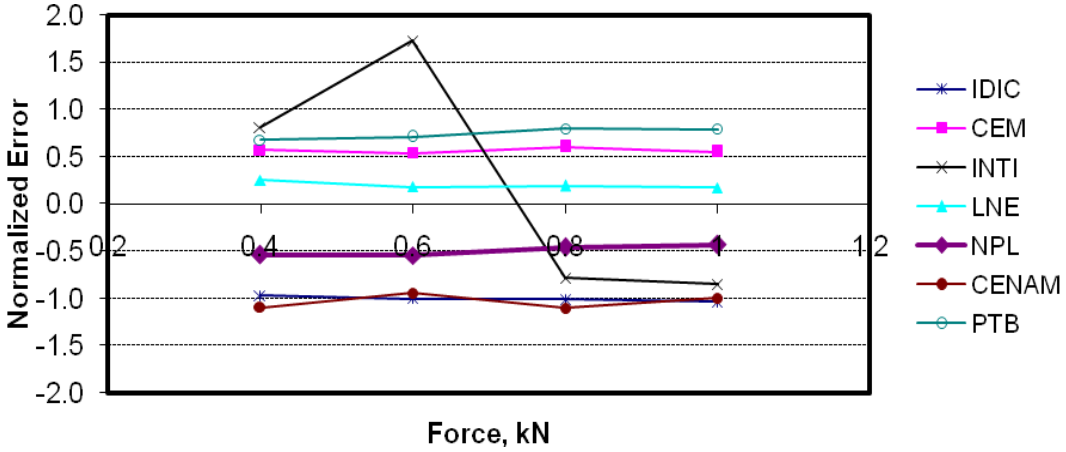

Figure 7. Normalized error equation graph for 1 kN force range. All participating laboratories.

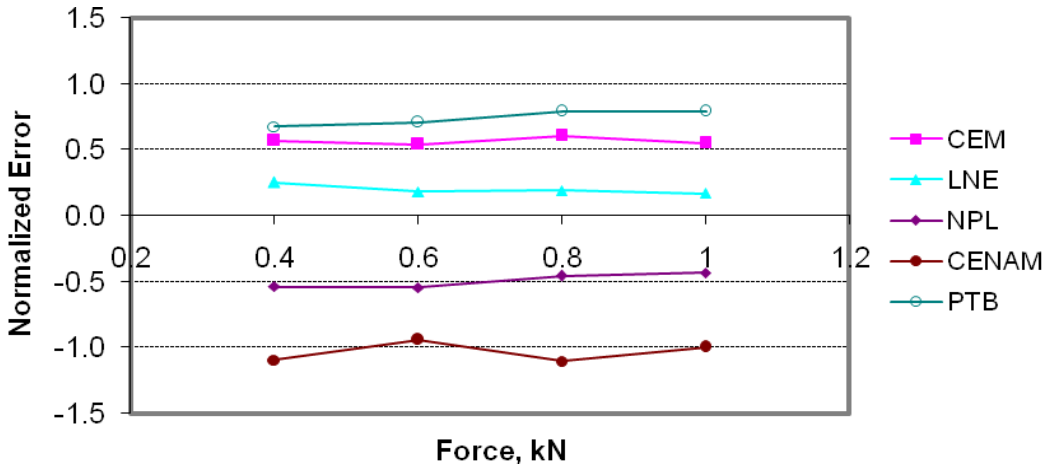

Figure 8. Normalized error equation graph for 1 kN force range. Primary laboratories only.

6. Conclusions

Three laboratories from SIM and four from Euromet compared their force standards by means of 2 force transducers. Figures 1 to 5 present the relative deviations for the range up to 1 kN, showing overlapping among the deviations and uncertainties reported by the laboratories.

As it can be seen in figures 7 and 8, the results demonstrated agreement among all laboratories for the range up to 1 kN. In this range only the measured point of 0.6 kN of the INTI results were above 1.5 of the values obtained by means of the normalized error equation; all the other results were very close or below 1.

In order to obtain better results the transfer standards used for the comparison should be improved (certainly that for the 50 kN range); nevertheless, the exercise was very useful to compare the values of force obtained by the different laboratories.

The comparison was performed with great wiliness from the laboratories, especially those from Euromet, who participated in a very short notice.

Acknowledgements

The authors wish to acknowledge the financial support given by the Sistema Interamericano de Metrologia (Interamerican Metrology System, SIM) and the Physikalisch-Technische Bundesanstalt (PTB, Germany), to meet the expenses of this exercise.

References

[1] International Vocabulary of Basic and General Terms in Metrology; BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML; 1993.
[2] The International System of Units (SI); Bureau International des Poids et Mesures. BIPM; 1998.
[3] Guide To The Expression Of Uncertainty In Measurement; ISO TAG 4 WG 3. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML; 1995.
[4] Quinn T. J. Guidelines for key comparison carried out by Consultative Committees. 1997.

[5] Villarroel J. C., Torres-Guzman J. C. Giobergia L. R., General guidelines for the: Force national standards comparison within the Interamerican Metrology System (SIM), 1 kN and 50 kN. 2003.
[6] Villarroel J. C., Torres-Guzman J. C. Giobergia L. R., General procedure for the: Force national standards comparison within the Interamerican Metrology System (SIM), 1 kN and 50 kN. 2003.
[7] Torres-Guzman J. C., Sawla A., Ramirez D., Force Standards Comparison between PTB (GERMANY) and CENAM (MEXICO). Proceedings, Joint International Conference on Force, Mass, Torque, Hardness and Civil Engineering Metrology, IMEKO TC3/TC5/TC20, Germany. 2002.
[8] Torres-Guzman J. C., Ramirez D. A., Cruz P. J., Dead Weight Machines Comparison within the Interamerican Metrology System (SIM), up to 150 kN. Proceedings of the 17th International Conference in Force, Mass, Torque and Pressure Measurements, IMEKO TC3. Istanbul, Turkey. 2001.
[9] Li Qingzhong, Torres-Guzman J. C., Ramirez-Ahedo D. A., “Force Standards Comparison between CENAM (Mexico) and NIM (China)”, Simposio de Metrología 2002, Queretaro, Mexico, May 2002.