Proceedings, Joint International Conference on Force, Mass, Torque, Hardness and Civil Engineering Metrology
IMEKO TC3/TC5/TC20, 23 –27 September 2002. Celle, Germany.

FORCE STANDARDS COMPARISON BETWEEN PTB (GERMANY) AND CENAM (MEXICO).

Jorge C. Torres-Guzmán, Amritlal Sawla**, Daniel Ramírez-Ahedo**
* Centro Nacional de Metrología, México.
**Physikalisch-Technische Bundesanstalt, Germany.

Abstract. A force comparison was carried out between the Centro Nacional de Metrología, CENAM (in Mexico) and the Physikalisch-Technische Bundesanstalt, PTB (in Germany), 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 a range starting at 2 kN and up to 150 kN. In order to achieve best accuracy of the force transducers used was made of 5 sub ranges (5 kN, 20 kN, 50 kN, 100 kN and 150 kN). The results obtained, the deviations graphs that include the uncertainty for each laboratory are presented in this document.

1. Introduction

Within the frame of the Physikalisch-Technische Bundesanstalt (PTB, Germany) - Centro Nacional de Metrología (CENAM, Mexico) collaboration, a force comparison 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 institutions.

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 in the range of 2 kN to 150 kN.

2 Comparison

2.1 Comparison standards

In order to achieve best accuracy of the comparison force transducers used, the range was divided in 5 sub ranges, as shown below.

Instrument	Make	Comparison Sub Ranges	Force Steps
Digital Amplifier (PTB)	HBM	-	-
Digital Amplifier (CENAM)	HBM	-	-
Force Transducer up to 5 kN	HBM	2 kN to 5 kN	2 kN, 3 kN, 4 kN and 5 kN
Force Transducer up to 20 kN	GTM	10 kN to 20 kN	10 kN, 12 kN, 16 kN, and 20 kN
Force Transducer up to 50 kN	GTM	20 kN to 50 kN	20 kN, 30 kN, 40 kN, and 50 kN
Force Transducer up to 100 kN	GTM	50 kN to 100kN	50 kN, 60 kN, 80 kN, and 100 kN
Force Transducer up to 150 kN	GTM	100 kN to 150 kN	100 kN, 120kN, 140 kN and 150 kN

Table 1. *Comparison general information.*

2.2 Comparison round

The comparison was performed including initial measurements at the PTB force laboratory, measurements at CENAM and final measurements at PTB.

2.3 General guidelines and procedure

The most relevant aspects of the measurements procedure and comparison conditions are included in tables 1 and 2.

Readings positions	0°, 90°, 180°, 270° and 360°
Readings cycles	2 cycles in each position and 1 cycle at 360°
Force application time	180 s
Preloads application time	180 s with 180 s resting time between preloads
Number of preloads (at maximum force)	3 at 0°, 2 at 90°, 180°, 270° and 360°
Temperature during measurements	22°C ± 0,3 K

Table 2. *Comparison procedure.*

3. Laboratories' standards

Both laboratories used dead weight machines (DWM) as their standards for the comparison. The information of the standards used by each laboratory is presented in table 3.

Sub Range	PTB	CENAM
2 kN to 5 kN	DWM-020k	DWM-CNM-150 kN
10 kN to 20 kN	DWM-020k	DWM-CNM-150 kN
20 kN to 50 kN	DWM-100k	DWM-CNM-150 kN
50 kN to 100 kN	DWM-100k	DWM-CNM-150 kN
100 kN to 150 kN	DWM-001M	DWM-CNM-150 kN

Table 3. *Dead weight machines (DWM) used for the comparison by the laboratories.*

4. Results

As PTB made two full measurements, these were analyzed to assess the stability of the force transducers. The two measurement results for each force transducer are presented in graphs, including deviation and uncertainty for each measurement and its mean value.

To increase clarity in the figures, a line is shown connecting the points of measurement.

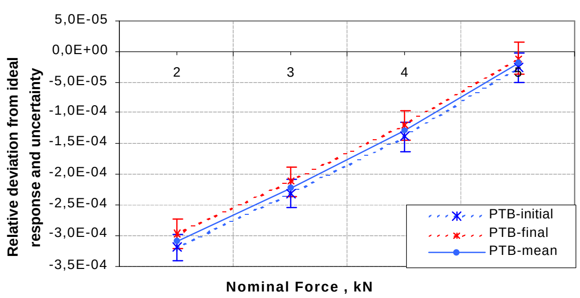

Figure 1. *PTB measurements to the force transducer for the 2 kN to 5 kN sub range.*

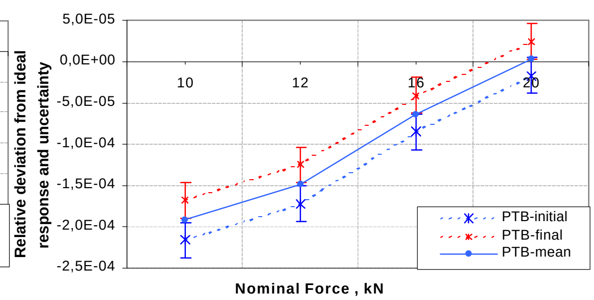

Figure 2. *PTB measurements to the force transducer for the 10 kN to 20 kN sub range.*

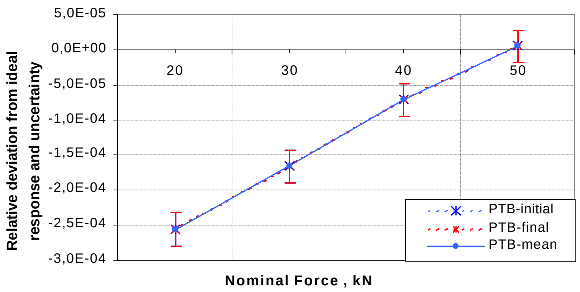

Figure 3. *PTB measurements to the force transducer for the 20 kN to 50 kN sub range.*

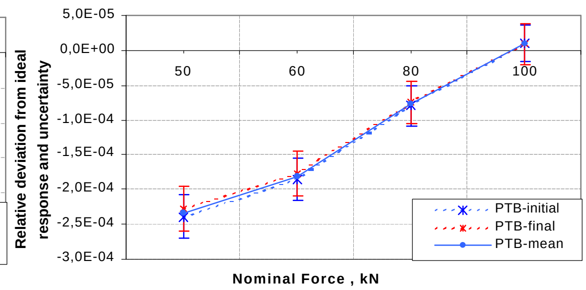

Figure 4. *PTB measurements to the force transducer for 50 kN to 100 kN sub range.*

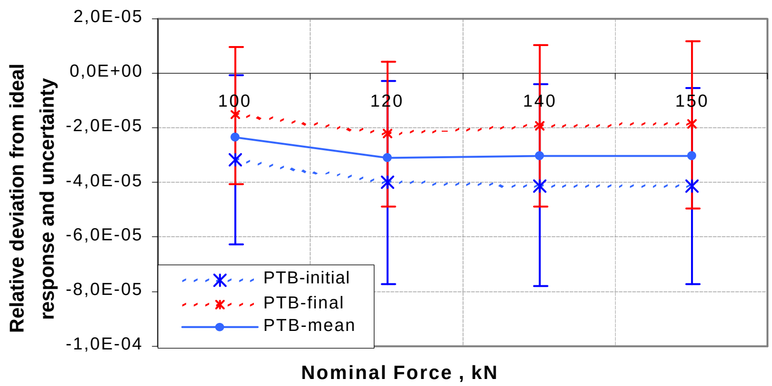

Figure 5. *PTB measurements to the force transducer for the 100 kN to 150 kN sub range.*

As it is shown in the previous figures, a very small time dependant variation on the instrument's response was detected. This small drift seems to be force dependent too. To compensate this effect, a no linear correction would have to be made; as the maximum drift during the period of the comparison is less than 50 10^{-6} relative to the applied force (only for one of the force transducers, figure 2), the correction of this effect seems to be unnecessary.

The results of the measurements made are here presented for each sub range. The results are shown in figures, one figure for each sub range. The figures 6 to 10, include the deviation and uncertainty calculated for the force transducer. In each figure, the points represent the results obtained by CENAM and the mean of PTB initial and final measurements. Similarly, the uncertainties presented for PTB are the mean value of their initial and final measurements.

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

- The uncertainties calculated were based mainly, on three contributing elements; the standard used by the laboratory, reproducibility of the results (which includes repeatability) and resolution of the comparison standard (force transducer and digital amplifier).
- The laboratories deviation was calculated respect to an ideal transducer response. The ideal transducer response used was to assume that the last preload applied to each force transducer represented its constant response behavior. Then, the laboratories measurement results were compared to this transducer response.

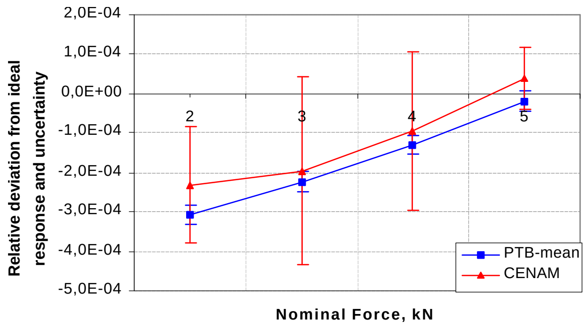

Figure 6. *Relative deviation PTB-CENAM for the sub range 2 kN to 5 kN.*

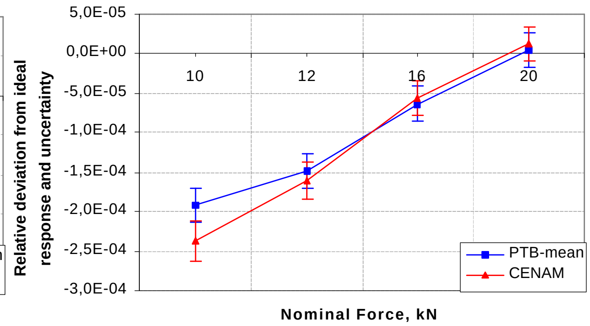

Figure 7. *Relative deviation PTB-CENAM for the sub range 10 kN to 20 kN.*

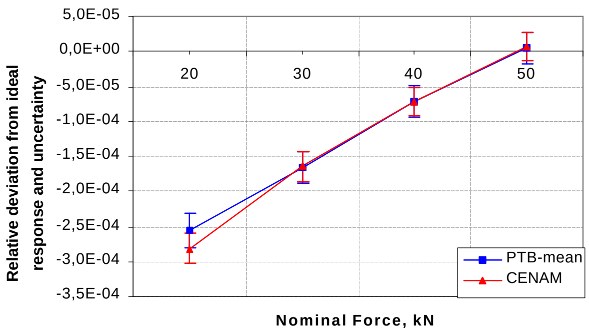

Figure 8. *Relative deviation PTB-CENAM for the sub range 20 kN to 50 kN.*

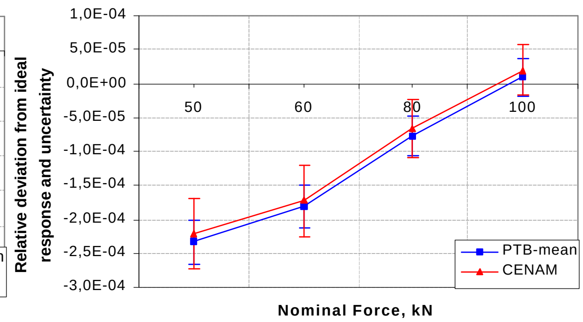

Figure 9. *Relative deviation PTB-CENAM for the sub range 50 kN to 100 kN.*

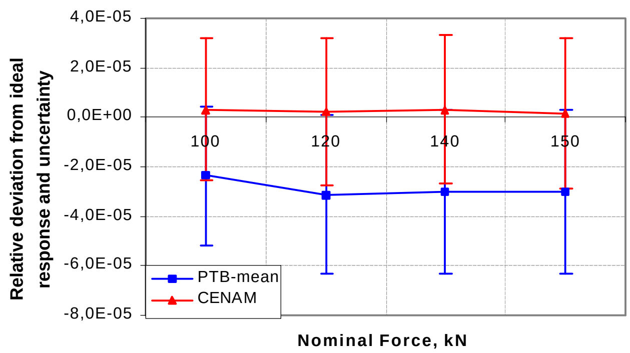

Figure 10. *Relative deviation PTB-CENAM for the sub range 100 kN to 150 kN.*

5. Discussion

From the five figures (figures 6 to 10), it can be observed that the laboratories uncertainties calculated for each force transducer are similar except for 2 kN to 5 kN where the uncertainty calculated by CENAM was higher (due to reproducibility). Also, the biggest difference between the results of the two laboratories occurred in figure 7 at 10 kN, where the uncertainties of the laboratories barely overlap each other.

In order to compare in a better way the measurement results, a normalized error graph can be used. A modified equation of the one described in NORAMET´s document 8 [5] and EAL-P7 [6] is proposed. The equation used here (equation 1) takes into account the initial and final readings performed at PTB. As readings were made in mV/V, the calculated deviation is 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 deviation (e_{CENAM} or $e_{PTB\text{-}mean}$)
e_{ref} - average estimated deviation = (e_{CENAM} + $e_{PTB\text{-}mean}$) / 2
U_{lab} - laboratory's expanded uncertainty (U_{CENAM} or $U_{PTB\text{-}mean}$)
U_{ref} - average expanded uncertainty (three options were used, see equation 2, 3 and 4)

In all calculations, the average from the PTB measurements was used to represent PTB, as:

$$U_{PTB\text{-}mean} = (U_{PTB\text{-}initial} + U_{PTB\text{-}final}) / 2$$

And,

$$e_{PTB\text{-}mean} = (e_{PTB\text{-}initial} + e_{PTB\text{-}final})/2$$

The three options for the reference uncertainty values used are:

1) Average.

$$U_{ref} = \left(U_{CENAM} + U_{PTB-mean}\right) / 2 \quad (2)$$

2) Combined uncertainty of the two laboratories.

$$U_{ref} = \sqrt{\left(U_{CENAM}^2 + U_{PTB-mean}^2\right)} / 2 \quad (3)$$

3) Combined and including the comparison's standard time stability.

$$U_{ref} = \sqrt{\left(U_{CENAM}^2 + U_{PTB-mean}^2\right)/4 + S_{stability}^2} \quad (4)$$

Where,

$$S_{stability} = \frac{\left|e_{PTB-initial} - e_{PTB-final}\right|}{2 \cdot \sqrt{3}} \quad (5)$$

The force transducer that presented the greatest drift is the one used for the sub range covering from 10 kN to 20 kN (figure 2). The variability range for its lower force point (figure 7), is $2a \leq 0{,}5 \cdot 10^{-4}$; then, the estimated standard deviation, in relative terms from the mean for 10 kN, is obtained as: $S_{stability} = 50 \cdot 10^{-6} \big/ \left(2 \cdot \sqrt{3}\right) = 14{,}4 \cdot 10^{-6}$

The normalized error equation presented here, is used to obtain a new set of graphs for all the sub ranges. It is important to point out that the values should be between –1,0 and +1,0 if equivalence of measurements is to be achieved [5, 6]. In order to provide a better view of the comparison results and of the equivalence of measurement, the next graphs present the most critical results (larger normalized error) from the three options for U_{ref}, option 2.

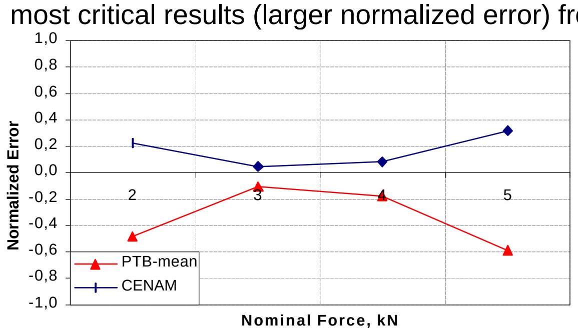

Figure 11. *Normalized error, (option 2), for 2 kN to 5 kN.*

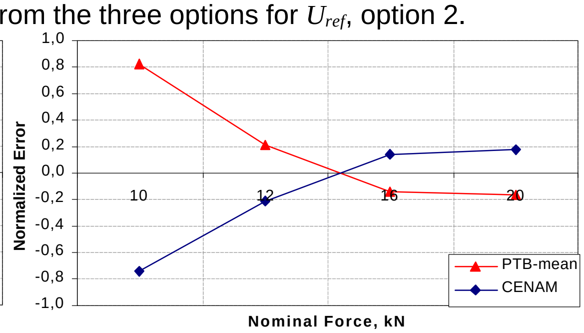

Figure 12. *Normalized error, (option 2), for 10 kN to 20 kN.*

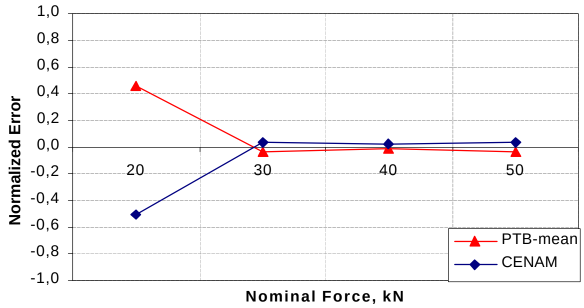

__Figure 13.__ Normalized error, (option 2), for 20 kN to 50 kN.

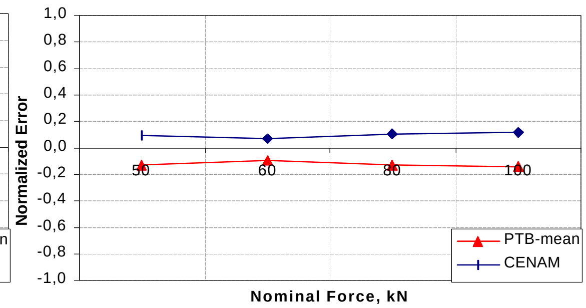

__Figure 14.__ Normalized error, (option 2), for 50 kN to 100 kN.

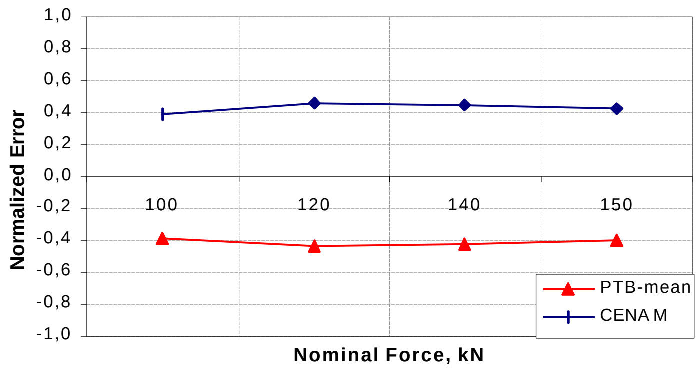

__Figure 15.__ Normalized error, (option 2), for 100 kN to 150 kN.

6. Conclusion

PTB and CENAM compared their force standards by means of 5 force transducers without performing preliminary measurements prior to the reported data. The transducers response was such as to facilitate the comparison. The results demonstrated agreement between the two laboratories with negligible differences observed. The normalized error equation employed has been proposed as means of assessing comparability between the two laboratories, and its use facilitated the visualization of compatibility of force measurement. The values obtained by means of the normalized error equation were, for almost all cases, below 0,5; only one point was 0,8 (10 kN, figure 12) and in many points below 0,2.

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] Document No. 8. Noramet. 1998.
[6] EAL-P7, EAL Interlaboratory Comparisons. 1996.

Contact Points

Dr. Jorge C. Torres-Guzmán
Centro Nacional de Metrología (CENAM)
km 4,5 carretera a Los Cués, El Marqués, Querétaro
C.P. 76 241, Mexico
Tel: (442) 211 0572, fax: (442) 211 0578
e-mail jtorres@cenam.mx.

Dr. Amritlal Sawla
Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100 D-38116, Braunschweig
Germany
Tel: (531) 592 1120, fax: (531) 592 1205
e-mail Amritlal.Sawla@ptb.de