SIM FORCE STANDARDS COMPARISON UP TO 10 kN

Jorge C. Torres-Guzmán, Daniel A. Ramírez-Ahedo

Centro Nacional de Metrología, CENAM. Mexico.

ABSTRACT

A comparison in the quantity of force was carried out among the SIM national laboratories in order to estimate the level of agreement for the realization of the quantity and the uncertainty associated to its measurement. This comparison was carried out up to 10 kN. The equipment used consisted on two force transducers (load cells); both with the same measuring range (10 kN). With the purpose of obtaining maximum accuracy on the transducers, the comparison range was selected from 4 kN up to 10 kN. This comparison provides a link to CIPM Key Comparisons. The results obtained, as well as the reference values selected for the comparison are included in this document. Two different methods were used to analyze the level of agreement and to state the conformity declaration.

1. INTRODUCTION

This force comparison was performed among national laboratories within the Interamerican Metrology System (SIM) region. Each laboratory used its national standard for the established measuring range. There were six participating NMIs from three different areas of SIM, Noramet, Andimet and Suramet. The reason the two other SIM areas did not participate in this comparison was that they did not count with standard with the required range. The Centro Nacional de Metrología (CENAM), Mexico, had the role of coordinator and pilot laboratory. The comparison started in August 2002 and finished in September 2004. In order to link this comparison with the CIPM Force Key Comparison CCM.F-K1.a and CCM.F-K1.b, the force points of 5 kN and 10 kN were measured in this comparison. This paper presents the results of the laboratories which used primary standards (dead weight machines).

2. SCOPE

The objective of the comparison was to estimate the level of agreement for the realization of the quantity and the uncertainty associated to its measurement up to 10 kN within the SIM region. Two transducers (load cells) were used as the comparison standard, to obtain its maximum accuracy, the comparison range was selected from 4 kN to 10 kN (starting at 40% of the full load cells range).

2.1 Participating Laboratories

Table 1. Participating laboratories.

SIM area	Laboratory	Person in charge	Country
Suramet	Centro de Física, Instituto Nacional de Tecnología Industrial (INTI-CEFIS)	Luis Giobergia	Argentina
	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO)	Jorge Cruz	Brazil
	Instituto de Investigaciones y Control del Ejército (IDIC)	Christian Villarroel	Chile
	Laboratorio Tecnológico del Uruguay (LATU)	Claudia Santo	Uruguay
Andimet	Centro de Control de Calidad y Metrología, Superintendencia Industria y Comercio (SIC)	Arisitides C. Dajer	Colombia
Noramet	Centro Nacional de Metrología (CENAM)	Jorge C. Torres	Mexico

2.2 Comparison Standard

The comparison standard was conformed of 2 transducers with the same range, but with different metrological characteristics. Each laboratory used its own electronic amplifier (DMP 40). A resistance calibrator was sent to allow corrections due to each amplifier possible deviations.

Table 2. Comparison Standard Data.

Transducer Type:	Load cell	Load cell	Resistance calibrator
Range:	1 kN to 10 kN	1 kN to 10 kN	-2,0 to 2,0 mV/V
Make:	HBM	HBM	HBM
Model:	C3H2	C3H3	K3608
Serial number:	F 44 067	G 51 316	023 520 014
Uncertainty ($k = 2$):	±0,010% of the reading	±0,031% of the reading	±0,0025% of full scale

2.3 General Guidelines and Procedure

The relevant aspects of the measurement protocol are summarized here, but they were carried out widely in [1] and [2]. Just a few relevant points are mentioned here:

a) The transducers measurements were made in mV/V. The reference temperature was 22 °C ± 1 °C.

b) The reading without a load was referred as the zero reading. The measurements on the comparison standard were performed strictly in ascending order up to the measuring force load.

c) The DMP40 resistance was verified before and after de measurements with the K3806 calibrator provided, in: 0,0 mV/V; 0,2 mV/V; 0,8 mV/V; 1,0 mV/V; 1,2 mV/V; 1,8 mV/V; 2,0 mV/V.

d) For both transducers, five measurements positions were used 0°, 90°, 180°, 270° y 360°.

e) The load application cycles for each position are shown in Figure 1.

f) After finishing the corresponding readings, each participating laboratory sent to the pilot laboratory, the complete data file report of the measurements, including the associated uncertainty

g) Each participating laboratory technical staff performed the measurements and it was their sole responsibility to fulfill the requirements of the agreed regulating documents of this comparison.
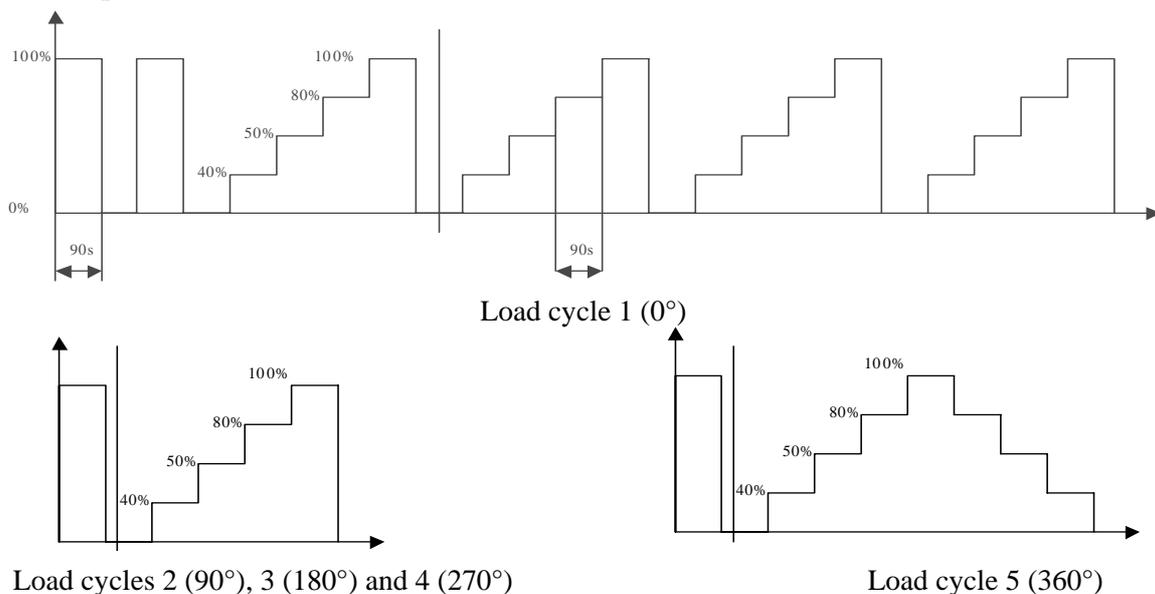

Load cycle 1 (0°)

Load cycles 2 (90°), 3 (180°) and 4 (270°)

Load cycle 5 (360°)

Figure 1. Comparison Load Cycles.

3.   PARTICIPATING LABORATORIES' STANDARDS

Four of the participating laboratories used Dead Weights Machines (DWM) and 2 used Force Transfer Standard Machine (FTSM). In Table 3, general information of the standards from each laboratory is listed. The uncertainties declared are those included in the BIPM CMCs data base.

Table 3. Participating Laboratories' Standards General Information.

| Laboratory	Machine Type	Range	Declared Uncertainty
INTI-CEFIS, Argentina	DWM	1 kN – 110 kN	$300 \cdot 10^{-6}$
INMETRO, Brazil	DWM	1 kN – 110 kN	$20 \cdot 10^{-6}$
IDIC, Chile	FTSM	500 N – 50 kN	$500 \cdot 10^{-6}$
LATU, Uruguay	FTSM	1 kN – 10 kN	$600 \cdot 10^{-6}$
SIC, Colombia	DWM	100 N – 10 kN	$50 \cdot 10^{-6}$
CENAM, Mexico	DWM	500 N – 50 kN	$20 \cdot 10^{-6}$

4.   RESULTS

A spreadsheet in Excel was provided to register the measurements of each transducer and the readings obtained from the DMP40 with the K3806 [3]. The uncertainties calculated by each laboratory were based mainly on four contributing elements: the standard used by the laboratory, repeatability, reproducibility and resolution of the comparison standard (instrument). Each laboratory applied all necessary corrections to the measured force.

CENAM carried out five calibrations on the force transducers and the maximum difference among the various calibrations is presented in Graph 1 and Graph 2, for each of the 2 force transducers.
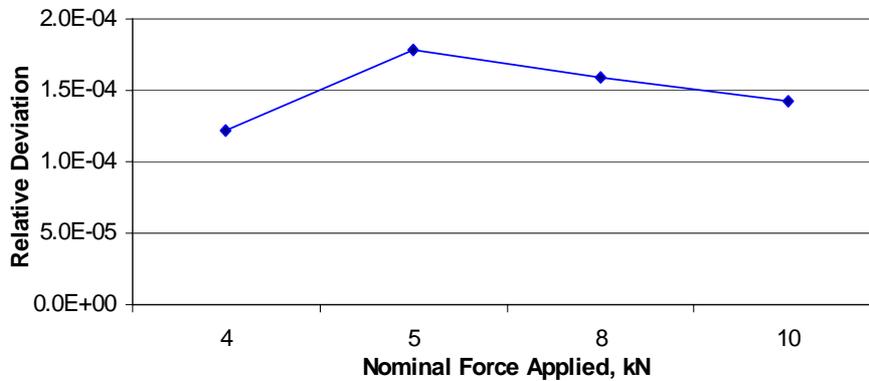
Graph 1. Maximum deviations for the force transducer G51316.
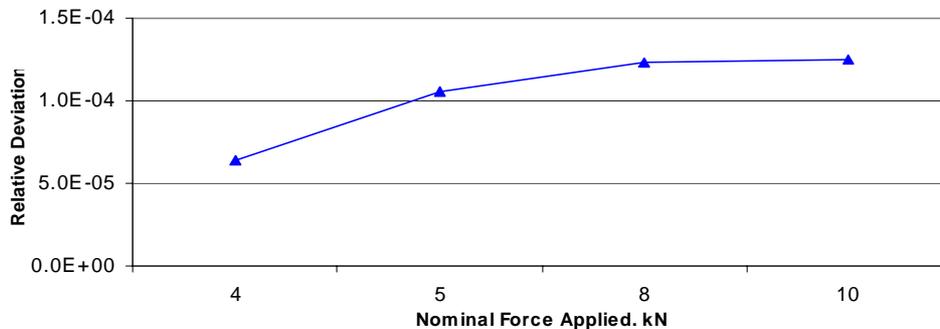
**Graph 2**. Maximum deviations for the force transducer F44076.

As it is shown in graphs 1 and 2, the stability during the complete period of the comparison is less than $180 \cdot 10^{-6}$ (relative to the applied force) for one transducer and less than $130 \cdot 10^{-6}$ for the other. For the worst case at 5 kN force point (force transducer G51316), the estimated standard uncertainty due to the transducer stability is, $u_{stability} = 0,9$ N / $2 \cdot (3)^{1/2} = 0,26$ N, which corresponds to $180 \cdot 10^{-6}$ in relative terms, as presented in Graph 1. For each force measurement point the transducer stability uncertainty can be estimated from:

$$u_{stability\ of\ transf\ .std.} = \frac{\left| r_{CENAM\ 5} - r_{CENAM\ 1} \right|}{2\sqrt{3}} \tag{1}$$

For the purposes of the comparison, the values presented for CENAM's measurements are the mean values of the different calibrations performed. Since INMETRO and CENAM are primary laboratories and declared the smallest uncertainties, the force reference values used for the comparison are the average measurements obtained by them.

$$V_{ref} = \frac{V_{INMETRO} + V_{CENAM}}{2} \tag{2}$$

The following two graphs, present the results for the measurements made to the two comparison transducers as described in Table 2. The SIC (Colombia) was unable to make measurements in the force transducer F44076.
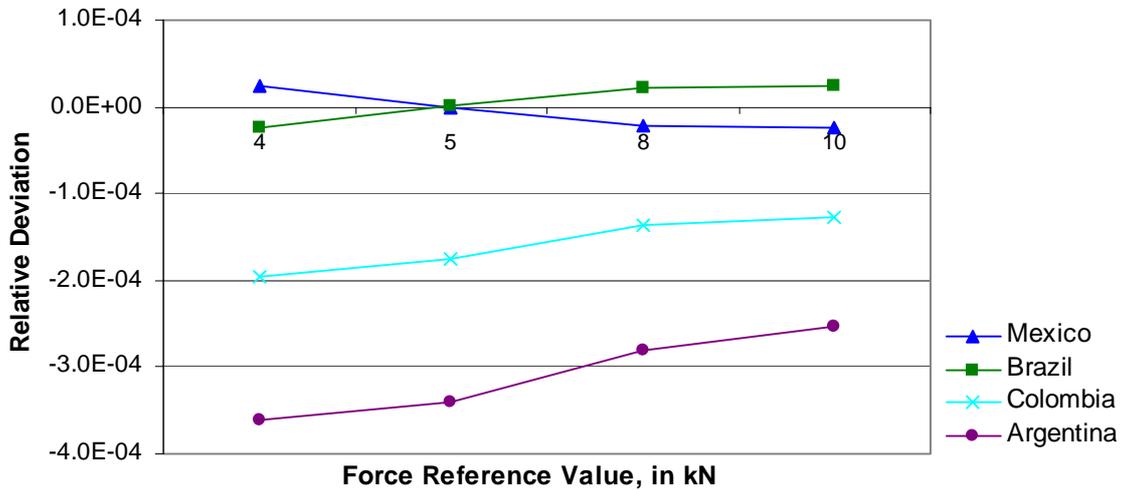
Graph 3. Relative deviation to the reference value of force with the force transducer G51316.
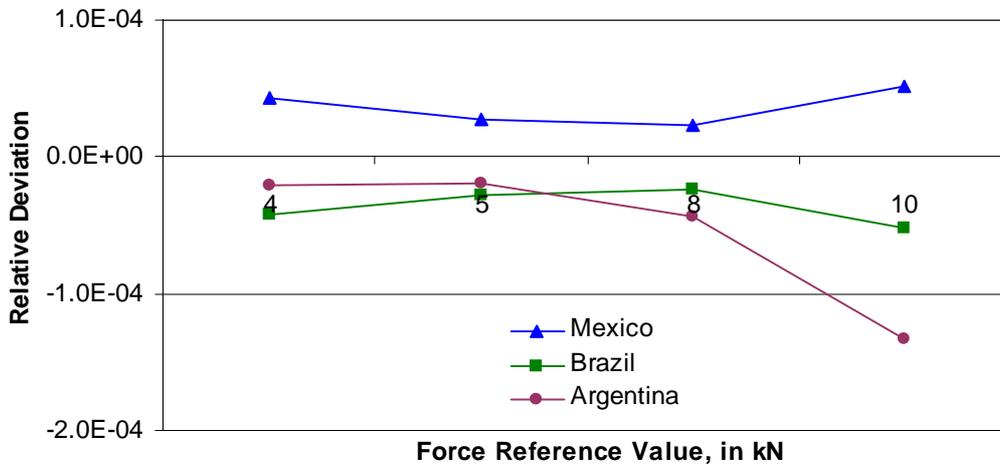
Graph 4. Relative deviation to the reference value of force with the force transducer F44076.

5. DISCUSSION

To compare (in a better way) the measurement results from the participating laboratories, the normalized error was calculated using a modified equation (such as in [4]) of the one described in NORAMET´s document 8 [5] and EAL–P7 [6]. Equation 3 is used to compare all laboratories with the reference value in one graph. The reference uncertainty is INMETRO's and CENAM's combined uncertainties and combining, as uncertainty, the transfer standard stability as indicated in equation (4).

$$e_n = \frac{V_{lab} - V_{ref}}{\sqrt{u_{lab}^2 + u_{ref}^2}} \tag{3}$$

Where, e_n - normalized error calculated at each calibration force
  V_{lab} - laboratory's force value
  V_{ref} - CENAM and INMETRO force measurements average
  u_{lab} - laboratory's standard uncertainty
 u_{ref} - CENAM and INMETRO combined standard uncertainty (see equation 4)

$$u_{ref} = \left[\left(u_{INMETRO}^2 + u_{CENAM}^2 \right) / 4 + u_{stability\ of\ transf\ .std\ .}^2 \right]^{1/2} \tag{4}$$

Graph 5 shows the normalized error equation graph for the force transducer G51316.
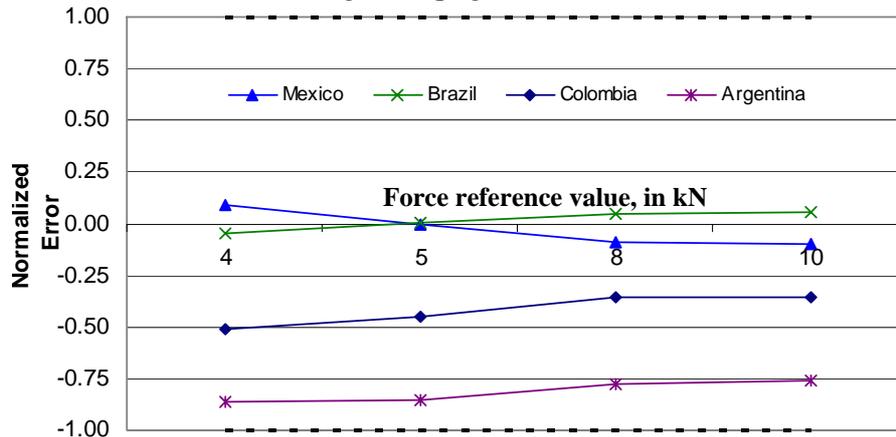

Graph 5. Normalized error (using standard uncertainty, $k=1$) for the force transducer G51316.

Graph 6 presents the normalized error equation graph results for the force transducer F44076. As previously said, SIC was unable to make measurements in this transducer.
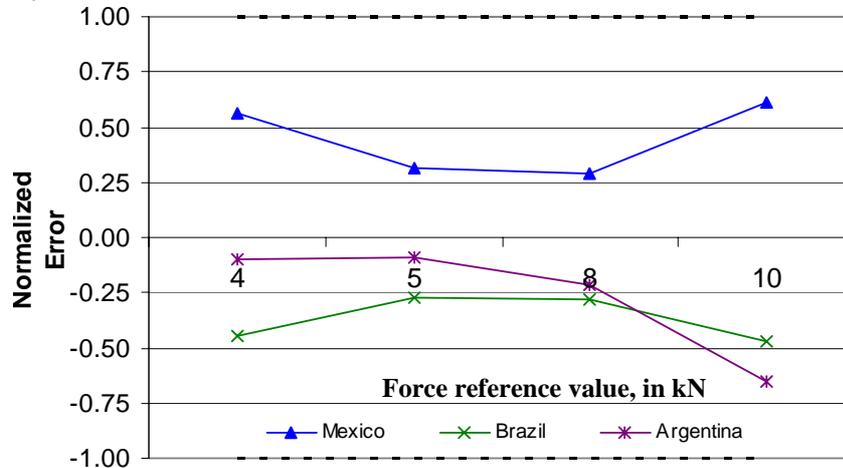

Graph 6. Normalized error (using standard uncertainty, $k=1$) for the force transducer F44076.

Since two force transducers were used, the Youden Plots [7] can be plotted to visualize the results of the comparison. Unfortunately, SIC measurements could not be included due to the fact that they were unable to make measurements to the force transducer F44076. Graphs 7, 8, 9 and 10 show the comparison results for each force measuring point. The standard reference uncertainty is included at the center.
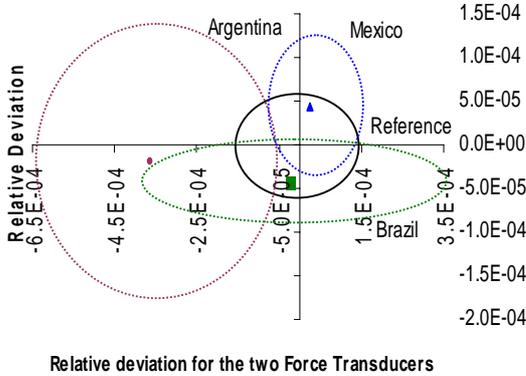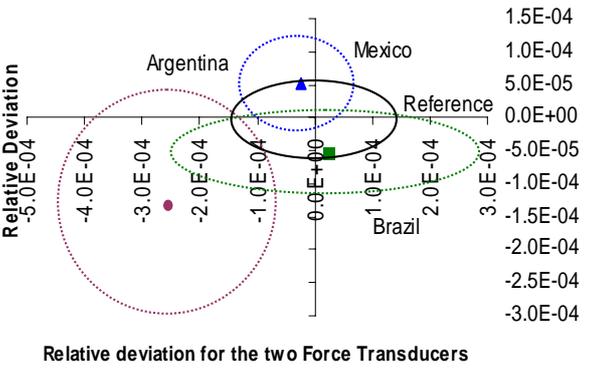

Graph 7. Youden Plot for 4 kN.
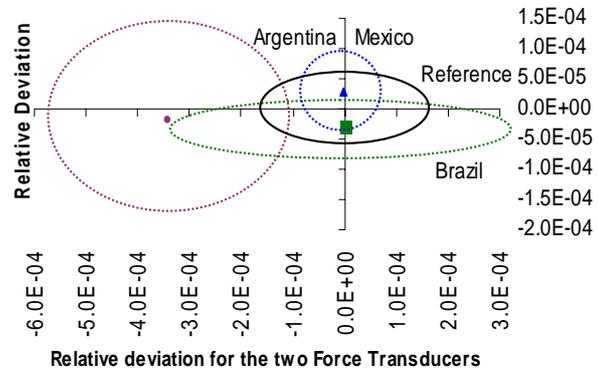
Graph 8. Youden Plot for 5 kN.
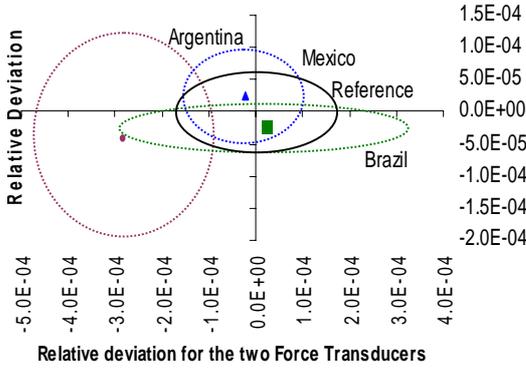
Graph 9. Youden Plot for 8 kN.

Graph 10. Youden Plot for 10 kN.

6.   CONCLUSIONS

Six national laboratories (INTI-CEFIS, IDIC, INMETRO, LATU, SIC and CENAM) compared their force standards by means of two force transducers without performing preliminary measurements prior to the reported data. Two of the national laboratories did not have primary standards and their declared uncertainties were higher. To keep adequate detail on the study their results will be presented separately.

In general, the results demonstrated agreement among the four primary national laboratories with negligible differences observed. It is important to notice the fact that the ISO standard uncertainties were used for the normalized error technique and for the Youden Plot results. This made the analysis of comparability among the laboratories more severe. Observing the results of comparability, the participating laboratories showed agreement within their declared uncertainties.

The normalized error equation that was used has been proposed as means of assessing comparability between the four laboratories, the Youden Plot was useful for the three laboratories which calibrated the two force transducers; the use of both techniques facilitated the visualization of compatibility of force measurement.

The values obtained by means of the normalized error equation were, for almost all cases, below 0,75; only one laboratory had two points on 0,8 (4 kN and 5 kN, graph 5). For many points was below 0,5.

The Youden Plot for the 3 compared laboratories showed full agreement between INMETRO and CENAM; when including the declared uncertainty INTI-CEFIS shows a good agreement with the reference values.

ACKNOWLEDGEMENTS

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Authors Addresses:

J. C. Torres-Guzmán, D. A. Ramírez-Ahedo, Force and Pressure Division, Centro Nacional de Metrologia.
km 4,5 carretera a Los Cués, El Marqués, Queretaro, Mexico
Telephone [+52] (442) 211 0572, fax [+52] (442) 211 0578
jorge.torres@cenam.mx   dramirez@cenam.mx