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NON PRIMARY STANDARDS SIM FORCE COMPARISON UP TO 10 kN

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Abstract. This force comparison was performed among IDIC (Chile), LATU (Uruguay) and CENAM (Mexico), national laboratories within the Interamerican Metrology System (SIM) region. Each laboratory used its national standard for the established measuring range. The comparison started in August 2002 and finished in September 2004. This comparison is the second part of a SIM primary standards comparison carried out with the participation of INMETRO (Brazil), INTI (Argentina) and SIC (Colombia), having CENAM as pilot laboratory, (SIM comparison number SIM 7.7). This comparison has an overlap with the force steps used in the CIPM Key Comparison CCM.F-K1.a and CCM.F-K1.b., force points 5 kN and 10 kN.

The objective of the comparison was to estimate the level of agreement for the realization of the quantity force and the uncertainty associated to its measurement in the range up to 10 kN. Two transducers (load cells) were used as transfer standards, 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). The results obtained by the participating laboratories were in agreement according to the analysis of comparability performed by the normalized error equation and the Youden plot techniques used.

Keywords: Comparison, force, load cells, SIM.

1. INTRODUCTION

Three NMIs participated in this comparison, from two different areas of the Sistema Interamericano de Metrología (SIM), form Noramet (CENAM, Mexico) and from Suramet (IDIC, Chile and LATU, Uruguay). Each laboratory used its national standard for the comparison's measuring range, from 4 kN up to 10 kN. CENAM had the role of coordinator and pilot laboratory.

The comparison started in August 2002 and finished in September 2004. This is the second part of a SIM primary standards comparison carried out among INMETRO (Brazil), INTI (Argentina) and SIC (Colombia), having CENAM as pilot laboratory (identified in the SIM data base as comparison SIM 7.7) [1].

This comparison has an overlap with the force steps used in the CIPM Key Comparison CCM.F-K1.a and CCM.F-K1.b., force points 5 kN and 10 kN. CENAM participated in this CIPM Key force Comparison.

The analyses of comparability among the laboratories was performed by using the normalized error equation technique [2, 3] and, as two force transducers were the transfer standards, the Youden Plot analysis [1, 4] was also employed.

2. SCOPE OF WORK

The objective of the comparison was to estimate the level of agreement for the realization of the quantity force and the uncertainty associated to its measurement in the range up to 10 kN. This comparison has been entered in the SIM's data base as comparison SIM.7.7.

2.1 Transfer standards (TS)

A pair of force transducers (load cells) was used as TS. The characteristics of the transducers, as stated by the manufacturer, are given in Table 1.

Table 1. Transfer standards data.

Force Transducer Type:	Load cells
Manufacturer:	HBM
Range:	1 kN to 10 kN
Model (A):	C3H2
Model (B):	C3H3
Serial number (A):	F 44 067
Serial number (B):	G 51 316
Accuracy Class (A):	±0,03% of the reading
Accuracy Class (B):	±0,02% of the reading

2.2 General Guidelines and Procedure

The general guidelines followed those of other international comparisons [5, 6, 7 and 8]. Measurement protocol relevant aspects are summarized here:

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

b) The zero reading was that without a load. The measurements on the transfer standard were performed strictly in ascending order, up to the measuring force.
c) Load application and rest time periods: 90 seconds.
d) 0°, 90°, 180°, 270° and 360° were the transducers positions for measurement.
e) The measured forces: 4 kN, 5 kN, 8 kN and 10 kN.
f) The force measurements for position 0°, included two preloads, one stepped preload and three force measurement cycles in ascending order.
g) The force measurements for positions 90°, 180° and 270°, included one preload and one force measurement cycle in ascending order.
h) The force measurements for position 360°, included one preload and one force measurement cycle in ascending and descending order.

A spreadsheet in Excel was provided to register the measurements for each transducer and the readings obtained from each laboratory's DMP40 with the supplied K3806.

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 transfer standard (instrument).

3. PARTICIPATING LABORATORIES' STANDARDS

CENAM used a Dead Weights Machine (DWM), IDIC and LATU used Force Transfer Standard Machines (FTSM). In Table 2, the laboratories standards general information is listed. The uncertainties declared are those included in the BIPM and SIM CMCs data bases.

Table 2. Participating laboratories' standards general information.

Laboratory	Machine Type	Range	Declared Uncertainty
IDIC, Chile	FTSM	500 N – 50 kN	500 x 10^{-6}
LATU, Uruguay	FTSM	1 kN – 10 kN	600 x 10^{-6}
CENAM, Mexico	DWM	500 N – 50 kN	20 x 10^{-6}

4. RESULTS

The results of the measurements made to the TS by the participating laboratories are presented in Tables 3 and 4.

Table 3. Force transducer A [F44067] calibration results.

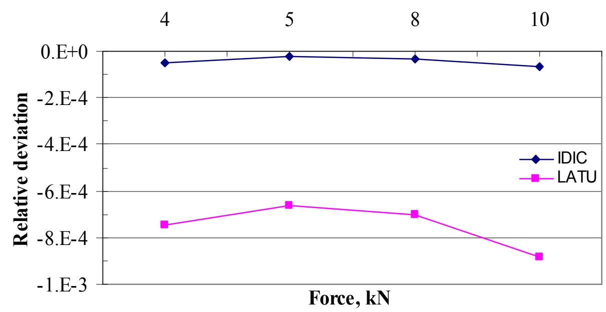
	CENAM		IDIC		LATU	
Force kN	Reading mV/V	U $k = 2$ 10^{-4}	Reading mV/V	U $k = 2$ 10^{-4}	Reading mV/V	U $k = 2$ 10^{-4}
4	0,815 930	0,61	0,815 890	4,9	0,815 322	5,0
5	1,019 926	0,76	1,019 902	6,1	1,019 249	7,6
8	1,632 052	1,2	1,631 999	9,8	1,630 903	13
10	2,040 245	1,3	2,040 110	12	2,038 438	16

Table 4. Force transducer B [G51316] calibration results.

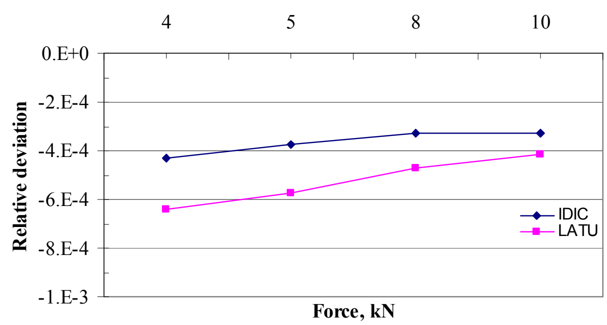
	CENAM		IDIC		LATU	
Force kN	Reading mV/V	U $k = 2$ 10^{-4}	Reading mV/V	U $k = 2$ 10^{-4}	Reading mV/V	U $k = 2$ 10^{-4}
4	0,815 380	0,79	0,815 028	4,9	0,814 856	7,2
5	1,019 210	0,88	1,018 828	6,1	1,018 622	11
8	1,630 835	1,6	1,630 298	9,8	1,630 063	23
10	2,038 724	2,1	2,038 057	12	2,037 879	31

On Tables 3 and 4, the readings for each laboratory are the average reading for the applied force found in the corresponding force transducer. The expanded uncertainty (U) is in mV/V.

Graphs 1 and 2, show IDIC's and LATU's relative deviations from the reference values (given by CENAM´s measurements).



Graph 1. Force transducer A [F44067] IDIC and LATU relative deviations form the reference values. Connecting lines have been superimposed over each laboratory's measurement results.



Graph 2. Force transducer B [G51316] IDIC and LATU relative deviations form the reference values. Connecting lines have been superimposed over each laboratory's measurement results.

5. DISCUSSION

The degree of equivalence among the results of the measurements made by the participating laboratories was evaluated using the normalized error equation according to the expression of Equation 1.

$$e_n = \frac{E_{Lab1} - E_{Lab2}}{\sqrt{(U_{Lab1})^2 + (U_{Lab2})^2}} \quad (1)$$

Where,

e_n - normalized error calculated at each force,
E_{Lab1} - estimated errors found by laboratory 1,
E_{Lab2} - estimated errors found by laboratory 2,
U_{Lab1} - estimated expanded uncertainty declared by laboratory 1,
U_{Lab2} - estimated expanded uncertainty declared by laboratory 2.

The results of the normalized error equation application by pairs are shown in Tables 5 and 6.

Table 5. Force transducer A [F44067] normalized error equation degree of equivalence between pairs of laboratories.

Force kN	IDIC/CENAM e_n	LATU/CENAM e_n	LATU/IDIC e_n
4	0,08	1,2	0,81
5	0,04	0,89	0,67
8	0,05	0,91	0,69
10	0,11	1,1	0,82

Table 6. Force transducer B [G51316] normalized error equation degree of equivalence between pairs of laboratories.

Force kN	IDIC/CENAM e_n	LATU/CENAM e_n	LATU/IDIC e_n
4	0,71	0,73	0,20
5	0,62	0,53	0,16
8	0,54	0,33	0,09
10	0,54	0,27	0,05

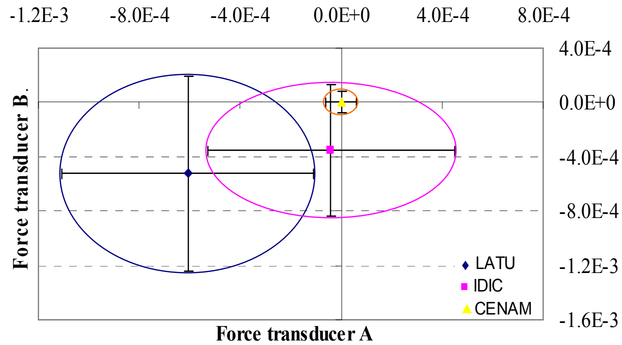
From Tables 5 and 6, it is important to notice that between IDIC and CENAM, the values were in excellent agreement throughout the entire comparison measuring force range. For the force transducer A [F44067], all values were below 0,15; for the case of the force transducer B [G51316], all values were below 0,75.

According to the normalized error equation values, LATU is in full agreement with CENAM and IDIC with the force transducer B [G51316]. The force transducer A [F44067] results, show a good agreement between LATU and IDIC for the entire measuring force range; with CENAM, force points 4 kN and 10 kN are just above 1,0.

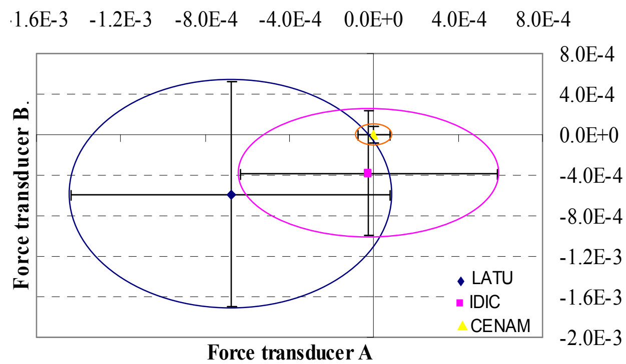
5.1 Youden Plot

Youden plots are a graphical technique for analyzing inter-laboratories data when each laboratory has made two sets of measurements on the same instrument or one run on two different instruments. In the ideal case (all laboratories from the same population), the Youden plot will have a structureless "random shotgun patter". Any structured deviation from this "random shotgun patter" suggests one or another laboratory is different from the rest. The advantages of the Youden plot are: Between laboratories differences are easy to detect (shifts along the diagonal for a given laboratory); within laboratory differences are easy to detect (displacement drawn with a fix size and with the base) [1].

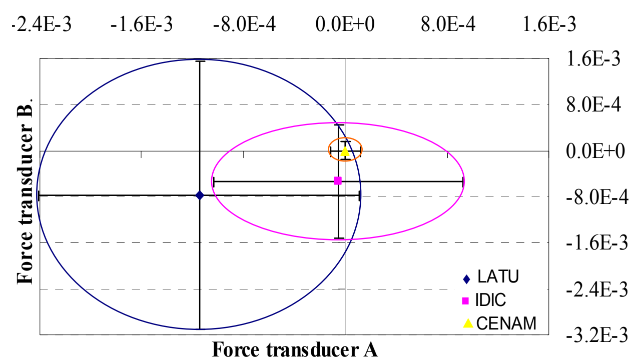
Since two force transducers were used, the Youden Plots can be plotted to visualize the results of the comparison. Graphs 3, 4, 5 and 6 show the comparison results for each force measuring point. The results from CENAM are considered reference values and are included at the center of the Graphs (cero deviation). For the Graphs, in the abysses axis are the results of measurements on the force transducer A [F44067]; in the ordinates axis are the results of measurements on the force transducer B [G51316].



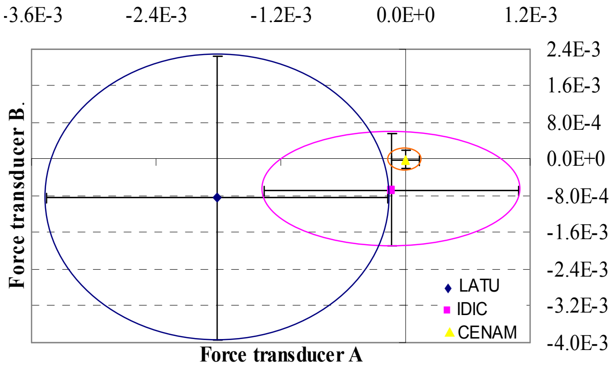
Graph 3. Force point 4 kN Youden plot for the relative deviations (center point of the circles) of IDIC and LATU and expanded uncertainty declared by each laboratory.



Graph 4. Force point 5 kN Youden plot for the relative deviations (center point of the circles) of IDIC and LATU and expanded uncertainty declared by each laboratory.



Graph 5. Force point 8 kN Youden plot for the relative deviations (center point of the circles) of IDIC and LATU and expanded uncertainty declared by each laboratory.



Graph 6. Force point 10 kN Youden plot for the relative deviations (center point of the circles) of IDIC and LATU and expanded uncertainty declared by each laboratory.

These graphs provide a better view of the comparison results and of the equivalence of measurements among the participating NMIs. Here, it can be noticed that IDIC and CENAM have an excellent agreement for the entire force comparison range.

LATU has a good agreement with IDIC and CENAM for the 5 kN and 8 kN force measuring points. At the force measuring points 4 kN and 10 kN LATU has an agreement with IDIC.

6. CONCLUSIONS

The use of both techniques facilitated the visualization of compatibility of the force measurements among the participating laboratories.

From the results of the analysis of comparability, normalized error equation and Youden plots, it can be concluded that excellent agreement exists among the measurements carried out by IDIC and by CENAM in the entire chosen range for this comparison from 4 kN up to 10 kN.

LATU has good agreement with IDIC for the entire force measuring range from 4 kN up to 10 kN; with CENAM, LATU has good agreement for the measuring force points 5 kN and 8 kN.

Form the relative deviation Graphs 1 and 2, it can be noticed a small deviation for the measuring results from LATU for one of the force transducers (A [F44067]) which could be due to the force transducers centering on the transfer machine.

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