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Dead Weight Force Machines Comparison within the Interamerican Metrology System (SIM), up to 150 kN

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Abstract

A force comparison was carried out within the Interamerican Metrology System (SIM), in order to estimate the level of agreement for the realisation of the quantity, and the uncertainty associated to its measurement. The comparison participants were the National Metrology Institutes (NMI´s) from SIM with dead weight machines: United States of America, Brazil and Mexico. The comparison was carried out up to 150 kN, using a load cell as the standard, having $1 \cdot 10^{-5}$ relative repeatability. The "Centro Nacional de Metrología" (CENAM), in Mexico, was the co-ordinator and pilot laboratory. The results obtained, deviations graph including the uncertainty for each participant laboratory are presented in this document.

1. Introduction

The realisation of the force quantity is a task assigned to the National Metrology Institutes (NMI´s), which are in charge of the correct dissemination of this quantity as well as giving the adequate levels of uncertainty to the traceability chain, according to the country's needs. Within the frame of the Interamerican Metrology System (SIM), a comparison was carried out in order to estimate the level of agreement for the realisation of the quantity of force, and the uncertainty associated to its measurement.

The comparison was performed among laboratories using similar standards (Dead Weight Force Machines). The SIM members have always had a keen interest in comparing their capabilities to realise the quantity of force. Until now, a force comparison within the SIM countries had not been performed. This comparison was carried out up to 150 kN (using a load cell).

2. Scope of Work

The ISO publication "International Vocabulary of Basic and General Terms of Metrology" (VIM) [1], and the International System of Units [2], SI, was used for the comparison and for the writing of this document. The recommendations established in the Guide to the Expression of Uncertainty in Measurement [3], were followed for the uncertainty evaluation.

2.1. Program Objectives

This comparison is the second part of two, both of them have the same measurement range; this comparison was held among SIM primary national laboratories, the first part was performed among SIM secondary national laboratories [4] (having transfer machines as national standards). For this comparison a document including general guidelines and procedure [5] was produced as well as a data sheet [6].

2.2. Participating Laboratories

There were three participating NMI´s, which are listed in table 1. The table presents the person in charge of the comparison for each laboratory. The Centro Nacional de Metrología, CENAM, acted as the co-ordinator and pilot laboratory.

Table 1. Participating laboratories.

Laboratory	Person in charge	Country
INMETRO	Jorge P. Cruz	Brazil
NIST	Simone Yaniv	USA
CENAM	Jorge C. Torres	Mexico

2.3. Comparison Standard

The following table contains the most relevant information of the transducer used as comparison standard.

Table 2. Comparison standard data.

Transducer Type:	Load cell
Range:	20 kN to 200 kN
Accuracy Class:	00
Uncertainty:	$40\ 10^{-6}$ (60 kN to 150kN)
Make:	HBM
Model:	C3 H3
Serial number or Identification:	H 046 55

The load cell was used with a digital amplifier HBM DMP40S2 serial number 962720029. Both, the load cell and the amplifier, belong to CENAM.

2.4. General Guidelines

The general guidelines for the comparison were established in the document [5] mentioned in 2.1; this document is based on the Guidelines for key comparisons by Terry Quinn [7]. Only a few relevant aspects of the measurement protocol are mentioned in this paper:

a) General regulations; In this part of the guidelines, several aspects were established such as, responsibilities, participation, schedule of the comparison, logistics and comparison devices to be used.
b) Measurement conditions; The following subjects regarding measurement conditions were also cover in the

guidelines: indicating device used, environmental conditions, load cell interaction with the machine and reading time interval.

2.5. Measurement Procedure

The reading and force step criteria were agreed and the main points of the measurement procedure are here described.

a) In order to evaluate and minimise the parasitic components [8], the load cell was measured in five different positions relative to the standard machine axis, in 0°, 90°, 180°, 270° and 360°;

b) In the 0° position, the load cell was preloaded three times to 100% of the range of measurement, during 90 s. Between preloads a pause of 180 s was made;

c) Then, two series of readings in ascending order were taken 180 s after the last preload and in the same mounting position (0°);

d) After these 2 series, the load cell was rotated 90° and was preloaded only once to 100% of the measurement range. Three minutes after unloading the cell, two series of measurements were taken in ascending order;

e) For the positions of 180° and 270°, the procedure of measurement was similar to that used for 90°. For the last position (360°), only one series of measurements was taken.

2.5.1 Force Steps and Readings Criteria

The forces applied by the standards, in the range of measurement and according to the restrictions of the loads, were determined with the following criteria:

a) The first 2 reading points were 60 kN and 70 kN. Then, 20 kN increments were made until the maximum value of 150 kN was reached; the force was held for 60 s at each measurement point before the reading was taken;

b) The same number and values of forces were applied in each series of measurement;

c) Readings were taken in mV/V.

3. Participating Laboratories Standards

The three participating laboratories used dead weight force machines as their standard for this comparison. Brazil used a dead weight force machine up to 110 kN and used a lever amplification system with the same machine up to 150 kN.

4. Results

The results of the measurements made by the participating laboratories were entered into the data file provided for the comparison[5] and sent to the co-ordinating laboratory. The uncertainties calculated by each laboratory

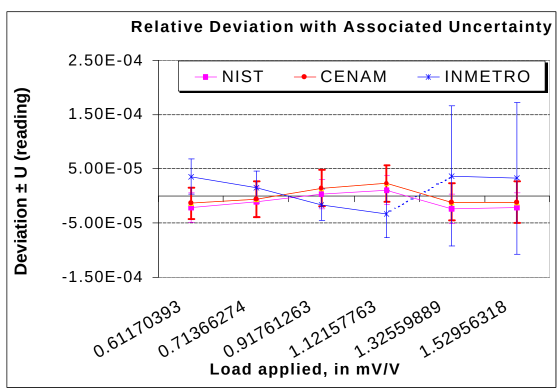

Figure 1. Relative deviation with associated

were based mainly on three contributing uncertainty elements: the standard used by the laboratory, repeatability and resolution of the comparison standard (instrument); though, each laboratory made all the corresponding corrections to the measured force and included some other contributing quantities into the uncertainty evaluation.

The resulting graphs, showing the error and uncertainty estimated for the instrument by each laboratory, are presented in this section. In an attempt to increase clarity in the graphs, lines for each laboratory connect the measured points. In figure 1., the relative deviations for each laboratory are plotted. The deviations are respect to the participants' average and to full scale.

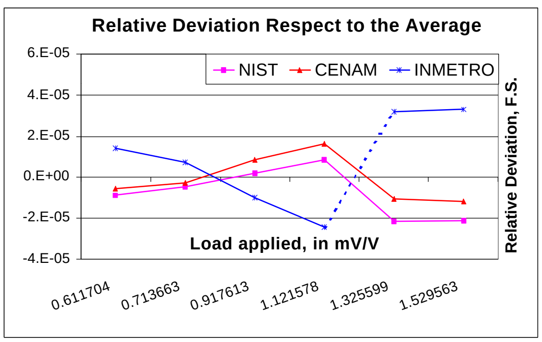

Figure 2. Relative deviations respect to the average and full scale.

Figure 2 includes the same information as in figure 1 and adds the uncertainty assigned by each laboratory.

Figure 3 shows the same information as figure 2, relative deviation and uncertainty assigned by each laboratory. The difference respect to the reading between the two figures is that figure3 presents the results respect to the reading (instead to full scale).

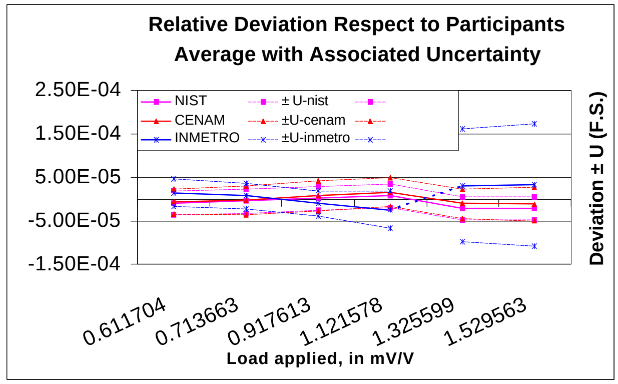

Figure 3. Relative deviations respect to the average and uncertainties. Reading.

5. Discussion

To compare in a better way the measurement results from the participating laboratories, a normalised error was obtained using equation 1 (proposed by Torres et al. [9], which is a modified equation of the one described in NORAMET´s document 8 [10] and SEA–2/03 [11]). The equation used here (equation 1) takes into account the results from the three laboratories and the aim is to compare the laboratories against the general average in one graph. The estimated error is considered instead of using a force lecture. Additionally, the reference values used in the equation are the average error and the combined uncertainty (as calculated by equation 2) obtained from the participating laboratories.

$$e_n = \frac{e_{lab} - e_{avg}}{\sqrt{U_{lab}^2 - U_{avg}^2}} \qquad (1)$$

Where,

e_n - normalized error

e_{lab} - laboratories estimated error

e_{avg} - average estimated error

U_{lab} - laboratory's expanded uncertainty

U_{avg} - average expanded uncertainty

$$U_{avg} = \sqrt{U_{NIST}^2 + U_{INMETRO}^2 + U_{CENAM}^2} \qquad (2)$$

Where,

U - expanded uncertainty declared by each laboratory.

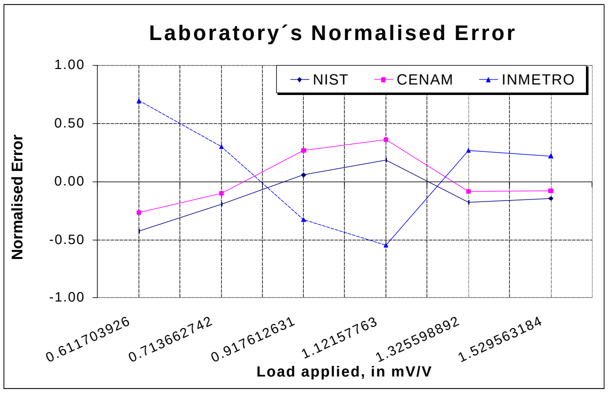

Figure 4. Laboratory's normalised error.

6. Conclusion

In this comparison, three national laboratories (INMETRO, NIST and CENAM) compared their force standards by means of an electronic transducer (load cell) with a digital amplifier, without performing preliminary measurements prior to the reported data.

The upper part of the compared range seems to present a small difference in graph 1 but when the same range is observed in graph 2, with uncertainties included, one can realise that the difference is negligible.

As it can be concluded by observation of graphs 2 and 3, no significant difference is obtained when plotting the graphs in respect to reading or full scale, mainly because the laboratories measurements average is use as reference.

The normalised error graph shows that agreement is reached among the three laboratories as none obtains a value greater than 1 [10].

The normalised error equation employed has been proposed as means of assessing comparability among laboratories. Other equations can be employed to compare results from the comparison [12] if desired, but as very good agreement was obtained it was judged unnecessary to make a deeper study in this subject.

Acknowledgements

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7. References

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