FORCE NATIONAL STANDARDS COMPARISON BETWEEN CENAM/MEXICO AND NIM/CHINA

Qingzhong Li *, Jorge C. Torres G.**, Daniel A. Ramírez A.**
*National Institute of Metrology (NIM)
Beijing, 100013, China
Tel/fax: (10) 6420 4788, e-mail: liqznim@hotmail.com
**Centro Nacional de Metrología (CENAM)
km 4,5 carretera a Los Cués, El Marques, Querétaro C.P. 76241, Mexico
Tel. 52 (442) 211 0572, fax: 52 (442) 211 0578, e-mail: jtorres@cenam.mx

Abstract: This paper presents the results of a force comparison between CENAM/Mexico, with a 150 kN dead weight machine (DWM), and NIM/China, with a 100 kN DWM. The procedures to calculate the uncertainty of the output of a calibrated force transducer and the relative difference uncertainty between two DWM, in compliance to ISO GUM 1995, are here included. Agreement of the force standards between China and Mexico is within 2E-5 relative to the reading. Uncertainty of the measurements made by both machines can be as good as 1E-5 relative to the reading as long as a good load cell is tested.

INTRODUCTION

Since the 1970's, many force comparisons have been done among national institutes, such as IMGC/Italy, PTB/Germany, NPL/U.K., NIM/China, UME/Turkey, CENAM/Mexico [1], [2], [3], [4], [5], [6]. Based on experimental results obtained, force agreement among European countries, American countries and Asian countries has been shown. The force difference was also obtained between Asia and Europe, Europe and America. But, there had not being a force comparison carried out between Asia and America. The question to be answered was: "what about the force agreement between the two continents?". To answer this important question, it was decided to carry out a force comparison between CENAM/Mexico and NIM/China during November/1998 -February/1999.

In this paper, the force difference between the two countries is given, as well as the uncertainty evaluation of the test results, showing a complete view of the comparison results. Since CENAM had carried out force comparisons with NIST/USA and INMETRO/Brazil, force agreement among the four countries could be estimated [5], [6].

FORCE COMPARISON INFORMATION

Force Standard Machines Compared and Transfer Standards Used

The force standard machines compared were CENAM's 150 kN DWM (figure 1), made in Italy, and NIM's 100 kN DWM (figure 2), made in China. As transfer standards HBM compression load cells from NIM were used, with ranges of 100 kN and 50 kN.

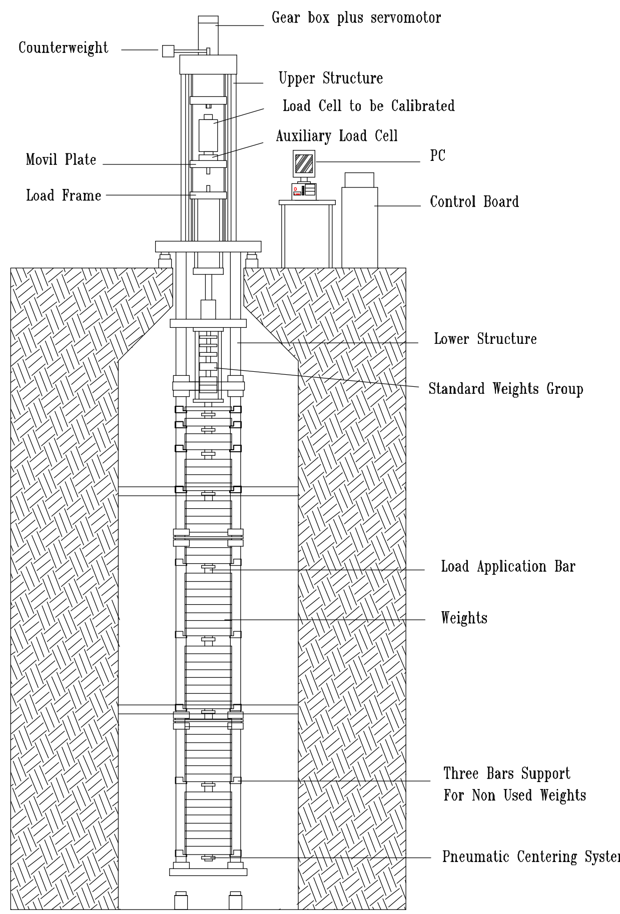

Fig. 1 *CENAM´s 150 kN dead weight machine.*

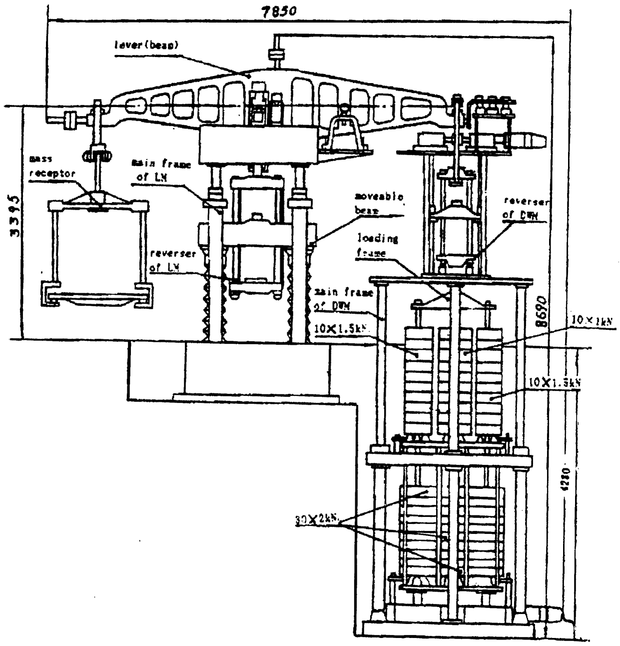

Fig. 2 *NIM´s 100 kN dead weight machine.*

Method Used for the Comparison

The load cells were first tested in NIM (data results denominated as NIM1), then tested in CENAM (data results denominated as CENAM). Finally, a second test was carried out again in NIM (data results denominated as NIM2). Each load cell was calibrated according to the following procedure:

- The force range tested was from about 30% up to 100% of each load cell capacity.
- Three pre-loadings at 0º position were made. The last pre-loading was done step by step.
- Three test cycles were made with increasing loads from about 30% up to 100% of the load cell capacity, step by step. The reading time (reading dwell duration) was taken at 1 min, the zero reading time at 2 min.
- After one step by step pre-loading, one test cycle was performed with increasing loads at 90º position. The same procedure was followed for 180º and 270º positions.
- At a 360º position, one step by step pre-load was performed. Then, one full test cycle with a step by step increasing and decreasing force was done.
- Based on the data obtained at a 0º position, the repeatability was calculated.
- Average measurements for the four positions were calculated from the 90º, 180º, 270º positions data and the last cycle at a 0º position measurement.
- The reproducibility was calculated from the data obtained at 0º, 90º, 180º and 270º positions. The hysteresis was obtained based on the 360º position full test cycle.
- According to the data of NIM1 and NIM2, the mean values for each load cell were calculated. Then, the relative deviations between CENAM and NIM were obtained.
- The uncertainty evaluation of the mean measurements of the load cells calibrated with NIM´s machine and CENAM´s machine had also been done, as well as the relative deviation uncertainty.

COMPARISON RESULTS

By means of the 100 kN and 50 kN load cells, the force relative deviations for the range from 20 kN to 100 kN between CENAM´s 150 kN DWM and NIM´s 100 kN DWM was obtained, being within 2E-5 relative to the reading (figures 4 and 6). For the uncertainty evaluation, there are two issues to consider: the average measurements uncertainty for the calibrated load cells [7], [8], and the force relative deviation uncertainties.

Uncertainty of the Average Measurements

There are five factors which contribute to the load cell´s average measurements uncertainty: repeatability R, reproducibility (or also called rotation effect) R_{ot}, zero-return Z_r, resolution R_{es} of the display used and expanded uncertainty d_f of the force standard machine employed to calibrate the load cell. The R and R_{ot} can be calculated by statistical methods, while Z_r and R_{es} can be taken as type "B" uncertainties and assumed to have rectangular distribution. The d_f is also a type "B" uncertainty calculated by the primary laboratory using its own method (the normal and most recommended method is by following the GUM [8]).

The different factors mention above are all independent one from another and may vary from load cell to load cell.

In other words, the particular contribution of each factor to the combined uncertainty is totally dependant on the load cell characteristics (geometry, elasticity behavior, environment response, mechanical transducer response, electrical transducer response and display stability), and some may be affected by the force standard machine used by the primary laboratory (i. e. repeatability R, and reproducibility R_{ot}). The expanded uncertainty d_f of the force standard machine employed is independent of the load cell to be calibrated.

Relative Deviation Uncertainty

The uncertainty of the force relative deviation between two machines can be calculated as follows:

$$u_d = \sqrt{w_{x1}^2 + w_{x2}^2}$$

while,

$$w_{x1} = \frac{1}{2}\sqrt{w_{x11}^2 + w_{x12}^2}$$

w_{x11} -- first time average measurement relative expanded uncertainty with NIM's DWM

w_{x12} -- second time average measurement relative expanded uncertainty with NIM's DWM

w_{x1} -- average measurement relative standard uncertainty with NIM's DWM

w_{x2} -- average measurement relative standard uncertainty with CENAM's DWM

Two more factors contribute to the force relative deviation uncertainty: the load cell long-term stability and the temperature effect on its measurement. Both are load cell characteristics, completely independent of the laboratory standard machine used.

$$w_{sb} = \frac{S_b}{2*\sqrt{3}}$$

$$w_{st} = \frac{S_t*(t_{cenam} - (t_{nim1} + t_{nim2})/2)}{2*\sqrt{3}}$$

The main results are shown in figures 3 to 6. Figure 3 shows the measurements relative uncertainty for NIM´s 100 kN DWM at first, second and average measurements, as well as CENAM´s 150 kN DWM results, for the 100 kN load cell. The relative uncertainty for NIM's first and second measurements are expanded uncertainties. In order to facilitate the comparison, the average NIM's relative uncertainty is presented as standard relative uncertainty; CENAM 's results are also presented as standard relative uncertainty.

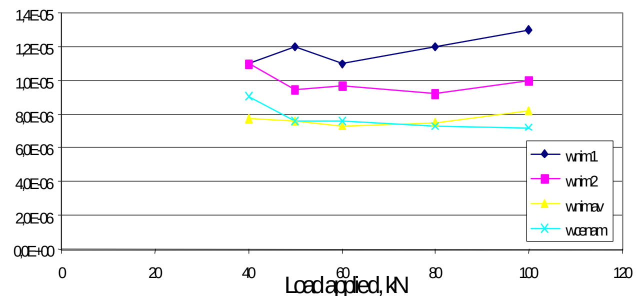

Fig. 3 *Measurements relative uncertainty for the 100 kN load cell.*

The next figure (figure 4) shows the resulting relative standard deviation between the two machines (dead weight machines from NIM and from CENAM) and the relative standard uncertainty estimated by each laboratory for the 100 kN load cell, at each measured force.

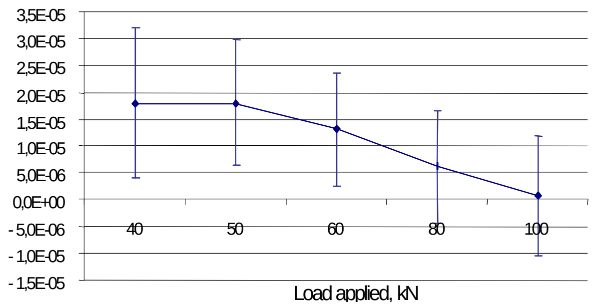

Fig. 4 *Relative deviation and its uncertainty for the 100 kN load cell.*

Figure 5 shows the measurements relative standard uncertainty for NIM´s 100 kN DWM first, second and average measurements, as well as the 150 kN CENAM´s DWM measurements for the 50 kN load cell. The relative uncertainty for NIM's first and second measurements are expanded uncertainties. In order to facilitate the comparison, the average NIM's relative uncertainty is presented as standard relative uncertainty; CENAM's results are also presented as standard relative uncertainty.

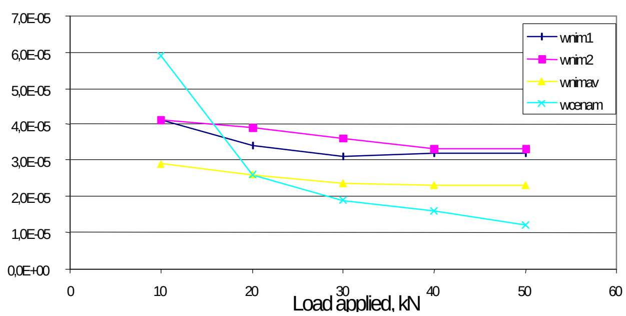

Fig. 5 *Measurements relative uncertainty for the 50 kN load cell.*

The next figure (figure 6) shows the resulting relative standard deviation between the two machines (dead weight machines from NIM and from CENAM) and the relative standard uncertainty estimated by each laboratory for the 50 kN load cell, at each measured force.

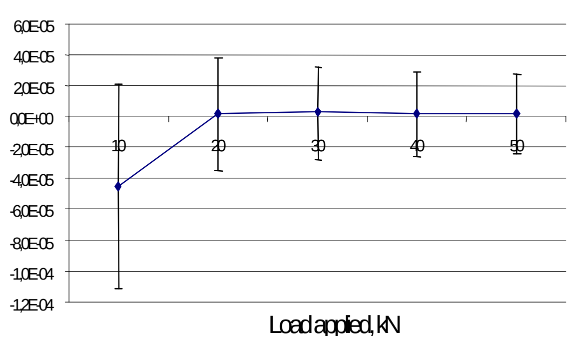

Fig. 6 *Relative deviation and its uncertainty for the 50 kN load cell.*

DISCUSSION

According to the measured data and the calculations made, within the five factors, the biggest contribution on the measurements relative uncertainty is the rotation effect, being more significant for the 50 kN load cell.

For this comparison, the contribution of the long-term stability on the relative deviation uncertainty is much smaller than others as well as the temperature effect. It would be true for all cases, as long as the load cell which is employed has a good long-term stability and a little temperature effect.

Since CENAM´s 150 kN DWM has lower rotation effect than NIM´s 100 kN DWM, the measurements relative uncertainty of CENAM´s machine is smaller than NIM´s machine for the 100 kN load cell as well as for the 50 kN load cell.

Alternative Method for the Rotation Effect Calculation

Besides the four positions method for reproducibility evaluation (by employing the measurements performed on 0º, 90º, 180º and 270º positions), it is also possible to use another method to calculate the reproducibility. This alternative method takes only the measurements at 90º, 180º and 270º positions to be used for R_{ot} calculation. The other associated calculations would have to be changed accordingly.

This method was discussed at the CCM force working group meeting held at NIST (Washington, USA, October 2001) and has been devised to avoid, including for a second time the repeatability effect, when the rotation effect is calculated.

The study of the two methods has been included in this work to assess the implications of the two different calculations on the results of a comparison.

The calculated results of the two methods are:

- The difference of the results calculated by the two methods for the 100 kN load cell is negligible, including the measurements average uncertainties at NIM and CENAM, and relative deviation uncertainties of the two machines.
- The difference of the results calculated by the two methods for the 50 kN load cell is more evident, as it is shown in figure 7. For most of the measured points the results obtained with the three positions are a little bigger than the ones obtained with the four positions used before.

- From the results obtained, it can be said that it is possible to assume the difference to be more significant for a load cell with a big rotation effect than for one with a small rotation effect.

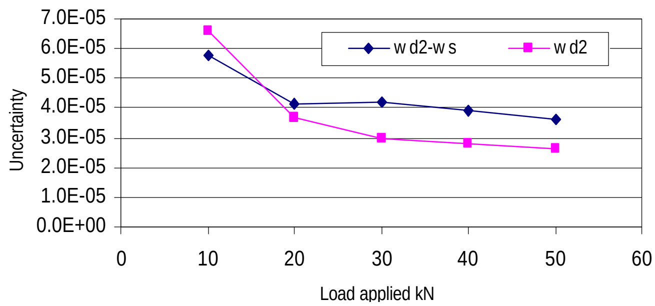

Fig. 7 *Difference of the results calculated by the two methods for the 50 kN load cell.*

CONCLUSION

As a result of this comparison, there are some conclusions that we would like to highlight.

- The agreement of the force standards between China and Mexico is within 2E-5 relative to the reading.
- The measurement uncertainties from both, CENAM´s 150 kN DWM and NIM´s 100 kN DWM can be as good as 1E-5 relative to the reading. As long as a good load cell is tested.
- It can be easily noticed that the results obtained with the three positions method are a little bigger than the ones with the four positions (used in the first part of this paper). Although, the difference between the two methods is not big and does not have an impact on the comparison results agreement, we will recommend a deeper study, for various cases.
- The procedure for the measurements uncertainty calculation could be used as a reference for other force comparisons as well as the method for the relative deviation uncertainty calculation.

ACKNOWLEDGEMENTS

NIM is grateful to Mr. Li Tingyuan, Metrology Institute of Space, Beijing China, for performing the comparison measurements.

CENAM wishes to acknowledge Fernando Martinez Juarez, from its Force and Pressure Division, for his contribution to the comparison measurements.

REFERENCES

[1] Sawla, A.; Peters, M,; Yaniv, S.; Metchell, R.: Intercomparison of force standard machines of NIST, USA, and PTB, Germany. PTB-MA-20, 1991, ISBN 3-89429-092-7.

[2] Ferrero, C; Qingzhong, L.: International comparisons of axial load in deadweight force standard machines by means of the IMGC 6-component dynamometer. XII IMEKO world congress, Beijing, China, 1991. Pages 172-177.

[3] Qingzhong, L; Ferrero, C.; Hwee, H.Y.: Intercomparison of force standard machines between China, Italy and Singapore. XIV IMEKO TC3, Warszawa (Poland), 1995. Pages 101-106.

[4] Qingzhong, L.: Agreement of force standards between China and other countries/regions, CCM working documents of the 7th meeting, May 1999.

[5] Torres Guzman J. C.; Ramirez Ahedo D.; Cruz J. P.: Dead weight force machines comparison within the Interamerican Metrology System, IMEKO TC3, Istanbul (Turkey), 2001. Pages 149-154.

[6] Torres Guzman J. C.; Ramirez Ahedo D.; Cruz J. P.; Saffar Jorge M. E.: Force Standards Comparison between Mexico and Brazil, IMEKO TC3, Istanbul (Turkey), 2001.

[7] EAL-G22 Uncertainty of calibration results in force measurements, 1996.

[8] ISO TAG 4 WG 3. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML; Guide To The Expression Of Uncertainty In Measurement; 1995.