

Comparison between the CENAM (Mexico) 150 kN and the INRiM (Italy) 1 MN force standard machines

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Abstract

The present paper describes the results of the bilateral comparison carried out between the CENAM (Mexico) 150 kN force standard machine and the INRiM (Italy) 1 MN Force standard machine. The two dead weight machines, their main metrological characteristics and the procedures of the comparison are described. Three different load cells (50 kN, 100 kN and 200 kN capacity) were used as transfer standards, and the test was made at 2 different load levels and at 5 angular positions for each load cell. The main results of the comparison with the relevant uncertainties from the measurements carried out at CENAM and at INRiM are presented and a final evaluation of the agreement between the two National force standard machines is given.

Keywords: force, measurement, force standard machine, comparison.

1. Introduction

The measurement of a physical quantity needs the establishment of a metrological chain, the starting point of which is the primary standard of the quantity. This standard must be transferable to secondary standards and to working standards having the required metrological characteristics. In Italy, the force standards are maintained at the INRiM – Turin; from 10 N to 1 MN, the primary standards are deadweight machines (DWM) having 2×10^{-5} relative expanded uncertainty (95% confidence level). In Mexico three deadweight force standard machines are used as national standards from 50 N to 150 kN. Their maximum relative expanded uncertainty is 2×10^{-5} ($k = 2$).

The comparison of the two largest national force standard machines of each laboratory was carried out in the framework of a project of scientific cooperation between the Italian and Mexican National Metrology Institutes. Although, both national laboratories have carried out a fair number of comparisons [1, 2, 3, 4, 5, 6, 7, 8, 9, 10], this constitutes the first force comparison between Italy and Mexico force primary standards.

2. INRiM and CENAM force standard machines

The standards involved in the comparison were the 150 kN CENAM deadweight machine and the 1 MN INRiM deadweight machine [11, 12]. The two standard machines are constructed by the same manufacturer with a similar design. They exhibit the following innovative characteristics:

- Weight pieces of austenitic stainless steel AISI 304.
- A supporting structure and a loading frame of the three-column type, to ensure a high stiffness along the different directions.
- Binary weight-piece combination.
- Individual suspension and transfer of the weight pieces.
- Balancing of the weight of the loading-frame and of the load-transmission system by means of a lever system.
- Maintenance of a constant load during load transient.

The binary weight-pieces combination lies in the possibility of performing self-calibrations of the weight pieces. Indeed, they can be calibrated directly on the machine with an uncertainty lower than 5×10^{-6} , by comparison with a single previously calibrated piece. In fact, the load substitution procedure is similar to the procedure proposed by Schoonover for big mass standard comparisons (1994). In this way, calibration can be made far quicker (since the number of weight pieces is small) and self-calibration can easily be repeated in the course of time, to check the stability of the standard. Self-calibration allows, additionally, a comparison to be made of the force generated by the different weight pieces directly at the level of the reference dynamometer.

A limit to calibration capabilities in deadweight machines is the weight of the loading frame. To overcome this difficulty, in both machines was adopted the solution of a balancing lever to compensate for the loading frame weight. In the 1 MN INRiM force standard machine the following weight pieces combinations were adopted (10 - 10 - 20 - 40 - 80 - 4 x 160 - 200) kN; therefore it is possible to generate a maximum load of 1 000 kN with 10 kN steps (Figure 1).



Figure 1. 1 MN and 30 kN INRiM force standard machines.

In the 150 kN CENAM force standard machine the following sequence of masses were adopted: 2 x 100 N; 200 N; 400 N; 800 N; 1 600 N; 3 200 N; 6 400 N; 12 800 N; 5 x 25 600 N. (Figure 2).



Figure 2. Weight pieces of the 150 kN CENAM force standard machine.

3. Comparison Measurements

The tests were first performed at INRiM (INRiM A) on April 2007, before shipping the instrumentation to CENAM, then at CENAM from 15th to 29th of June 2007 and finally at INRiM (INRiM B) on the end of June 2007.

3.1 Measurement devices

The measurements were carried out at three equally spaced load levels of the CENAM Force Standard Machine: 50 kN, 100 kN and 150 kN by using three different force transducers as force transfer standards (table I) [13].

The measurements were also programmed to evaluate for any overlapping effect.

Table I
Force transducers used for the comparison

LOAD [kN]	AEP KAL	LOAD CELLS	
	50 kN	HBM top-Z4A 100 kN	HBM top- Z4A 200 kN
0	0	0	0
50	50	50	100
		100	150

During the comparison the amplifier HB DMP 40 n. 0600420110 was used as reading device; the calibrator HBM BN100 n. 1987 was used to check the amplifier before and after any test.

3.2 Environmental conditions measurements

The measurements were carried out at (20 ± 0.5) °C air temperature. The environmental temperature near the force transducer, the relative humidity of the air in % and the barometric pressure were recorded.

3.3 Preparation of measurements

Before starting any measurements the force transfer standards and accompanying devices were allowed to reach the local environmental temperature for establishing thermal equilibrium, when already connected to the DMP 40. It was agreed that all measurements had to be carried out on the channel 1.1. The internal auto calibration had to be switched on during the measurements, the DMP 40 0.1 Hz Bessel filter and the resolution of 0.000 001 mV/V was used.

All measurements performed on each of the force transducers were carried out within one day.

- a) At first the DMP 40 was calibrated with the HBM BN 100 A.
- b) The measurements to the force transducer were then carried out.
- c) In the last step the DMP 40 calibration with the BN 100 A was repeated.

3.4 Measurement schedule

The following measurement schedule was programmed for each force transducer in the comparison: three preloads at 50 kN, 100 kN and 150 kN respectively, were applied; three measurement cycles at 0° angular position; one cycle at 90°, 180°, 270° and 360°/0° angular positions.

To minimise the effects of force transducers creep, each transducer calibration was carried out in accordance with a strictly-timed loading profile (see Figure 3), including the preloads which were always performed at the start of each test.

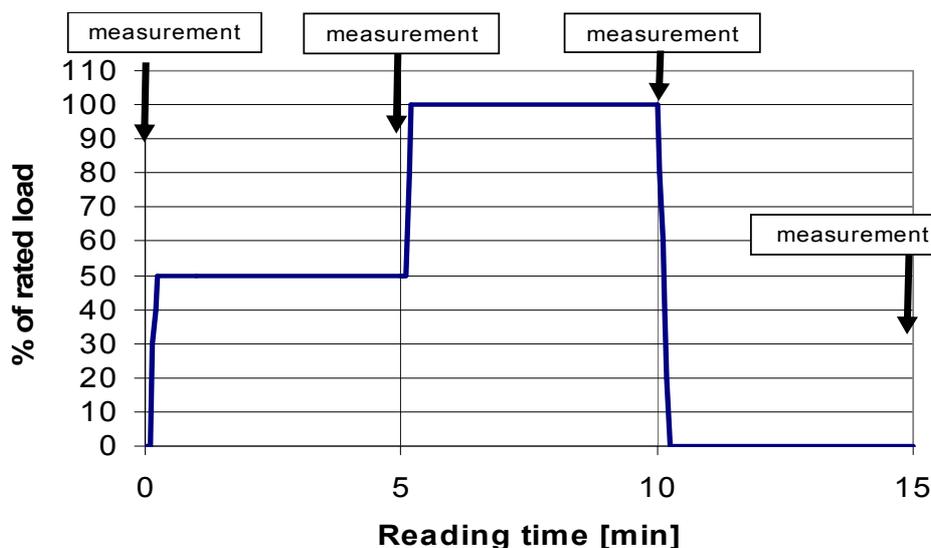


Figure 3. Loading diagram at each measurement cycle.

4. Experimental Results

4.1 Tests at INRiM

The first step of the comparison program was to carry out the tests on the INRiM 1 MN standard machine. In order to evaluate the reproducibility of the measurements, several tests were carried out for each load cell.

Table II shows the average of the load cell AEP Kal outputs at the five angular positions (0°, 90°, 180°, 270° and 360°) for three different tests and their means; also, the relative deviation, and the standard deviation and their expanded uncertainty of the measurements are given.

Table II
Tests at INRiM by using AEP 50 kN load cell

Load (kN)	INRiM A1 (mV/V)	INRiM A2 (mV/V)	INRiM A3 (mV/V)	Average (mV/V)	Relative Deviation	Rel. STD	<i>U</i>
50	1.999 956	1.999 956	1.999 955	1.999 956	7.9E-07	3.2E-07	2.0E-05

Table III shows the average, the relative deviation, the standard deviation and the expanded uncertainty of the measurements carried out between the tests on the 1 MN INRiM force standard machine (INRiM A and INRiM B) by using the AEP 50 kN load cell.

Table III
Results of test INRiM A and INRiM B at 50 kN (AEP load cell)

Load (kN)	INRiM A (mV/V)	Rel. STD	INRiM B (mV/V)	Rel. STD	Average (mV/V)	Relative Deviation	Rel. STD	<i>U</i>
50	1.999 956	3.2E-07	1.999 947	8.3E-07	1.999 952	2.2E-06	1.5E-06	2.0E-05

The same tests were carried out for axial load at 100 kN and 150 kN by using the HBM load cells. In tables IV and V the results obtained with the 100 kN HBM Z4A load cell, are summarised; in tables VI and VII the results obtained with the 200 kN HBM Z4A at 100 kN and 150 kN loads are indicated.

Table IV
Tests at INRiM by using 100 kN HBM Z4a kN load cell

Load (kN)	INRiM A1 (mV/V)	INRiM A2 (mV/V)	INRiM A3 (mV/V)	INRiM A4 (mV/V)	Average (mV/V)	Relative Deviation	Rel. STD	<i>U</i>
50	1.000 095	1.000 102	1.000 105	1.000 116	1.000 105	2.1E-05	6.0E-06	2.3E-05
100	2.000 085	2.000 095	2.000 090	2.000 097	2.000 092	1.2E-05	2.4E-06	2.1E-05

Table V
Results of test INRiM A and INRiM B at 50 kN and 100 kN by using HBM Z4a kN load cell

Load (kN)	INRiM A (mV/V)	Rel. STD	INRiM B (mV/V)	Rel. STD	Average (mV/V)	Relative Deviation	Rel. STD	<i>U</i>
50	1.000 105	6.0E-06	1.000 094	3.5E-06	1.000 099	1.0E-05	3.7E-06	2.1E-05
100	2.000 092	2.4E-06	2.000 067	2.7E-06	2.000 079	1.2E-05	4.3E-06	2.2E-05

Table VI

Tests at INRiM by using 200 kN HBM Z4a kN load cell

Load (kN)	INRiM A1 (mV/V)	INRiM A2 (mV/V)	Average (mV/V)	Rel. Deviation	STD	<i>U</i> rel.
100	1.000 357	1.000 359	1.000 358	1.7E-06	5.9E-07	2.0E-05
150	1.500 572	1.500 582	1.500 577	7.0E-06	3.0E-06	2.1E-05

Table VII

Results of test INRiM A and INRiM B at 100 kN and 150 kN by using 200 kN HBM Z4a kN load cell

Load (kN)	INRiM A (mV/V)	STD	INRiM B (mV/V)	STD	Average (mV/V)	Rel. Deviation	STD	<i>U</i>
100	1.000 358	1.2E-06	1.000 348	2.3E-06	1.000 353	1.0E-05	3.7E-06	2.1E-05
150	1.500 577	7.4E-06	1.500 565	2.4E-06	1.500 571	8.3E-06	2.9E-06	2.1E-05

4.2 Tests at CENAM

The tests were carried out on the 150 kN CENAM force standard machine by using the same three transfer standards and the tables VIII, IX and X show the main results of average, relative deviation and expanded uncertainty at the three different load levels (50 kN, 100 kN and 150 kN).

Table VIII

Test on the at CENAM by using the ARP 50 kN load cell

Load (kN)	CENAM (mV/V)	Rel. STD	<i>U</i>
50	1.999 915	1.9E-05	4.4E-05

Table IX

Test on the at CENAM by using the HBM 100 kN load cell

Load (kN)	CENAM (mV/V)	Rel. STD	<i>U</i>
50	1.000 116	1.1E-05	3.0E-05
100	2.000 102	2.4E-05	5.2E-05

Table X

Test on the at CENAM by usng the HBM 200 kN load cell

Load (kN)	CENAM (mV/V)	Rel. STD	<i>U</i>
100	1.000 379	2.7E-06	2.1E-05
150	1.500 610	1.6E-06	2.0E-05

4.3 INRiM-CENAM Comparison

The main results of the comparison between the two national standard machines are illustrated in the following tables. Table XI indicates the relative deviation between the results obtained on the INRiM and CENAM standard machines up to 50 kN and their expanded uncertainty.

In table XII are shown the results of measurements at 50 kN and 100 kN by 100 kN HBM Z4A load cell, and in table XIII the results of comparison up to 150 kN by using the 200 kN HBM Z4A load cell.

Table XI
INRiM-CENAM comparison up to 50 kN

Load (kN)	INRiM (mV/V)	CENAM (mV/V)	Rel. Deviation	<i>U</i>
50	1.999 952	1.999 915	-1.8E-05	4.8E-05

Table XII
INRiM-CENAM comparison up to 100 kN

Load (kN)	INRiM(mV/V)	CENAM (mV/V)	Rel. Deviation	<i>U</i>
50	1.000 099	1.000 116	1.7E-05	3.7E-05
100	2.000 079	2.000 102	1.1E-05	5.7E-05

Table XIII
INRiM-CENAM comparison up to 150 kN

Load (kN)	INRiM (mV/V)	CENAM (mV/V)	Rel. Deviation	<i>U</i>
100	1.000 353	1.000 379	2.6E-05	3.0E-05
150	1.500 571	1.500 610	2.6E-05	2.9E-05

5. Conclusions

On the basis of the results of the bilateral comparison of force standards between INRiM and CENAM detailed in the previous tables, it is possible to evaluate the relative deviations result to be as follow:

- -1.8×10^{-5} with an expanded uncertainty of 4.8×10^{-5} , at 50 kN by using AEP 50 kN load cell.
- 1.7×10^{-5} ($U= 3.7 \times 10^{-5}$) at 50 kN by using HBM 100 kN.
- 1.1×10^{-5} ($U= 5.7 \times 10^{-5}$) at 100 kN by using HBM 100 kN.
- 2.6×10^{-5} ($U= 3.0 \times 10^{-5}$) at 100 kN by using HBM 200 kN.
- 2.6×10^{-5} ($U= 2.9 \times 10^{-5}$) at 150 kN by using HBM 200 kN.

The value of the relative deviation between the two standard machines with the different load cells and their expanded uncertainty are shown in figure 4.

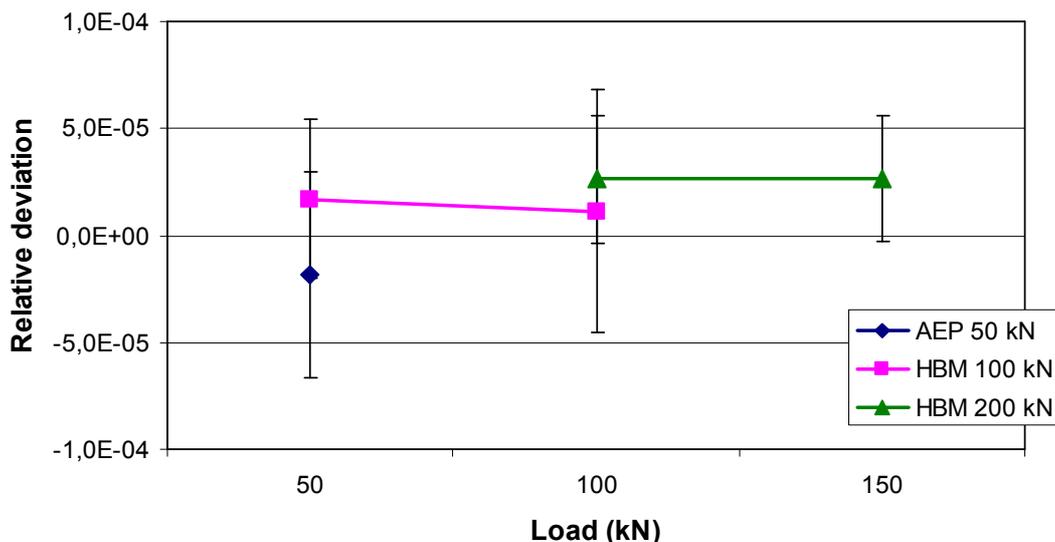


Figure 4. Relative deviation between the INRiM and CENAM force standard machines up to 150 kN.

One method for expressing the results of a bilateral comparison is to use the E_n value(1).

$$E_n = \sqrt{\frac{\bar{X}_{INRiM} - \bar{X}_{CENAM}}{(U_{INRiM})^2 + (U_{CENAM})^2}} \quad (1)$$

If the resulting E_n value is smaller than 1 it indicates that the difference between the two laboratories is non significant. In table XIV the E_n values are calculated for each load step and its results are always less than 1.

Table XIV
 E_n values calculated for three different load transfers

Load (kN)	Load cell type	E_n
50	AEP 50 kN	0.38
50	HBM Z4A 100 kN	0.46
100	HBM Z4A 100 kN	0.20
100	HBM Z4A 200 kN	0.89
150	HBM Z4A 200 kN	0.91

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