IMGC-CNR Activities to Improve the Force Chain in Italy

C. Ferrero and C. Marinari

Istituto di Metrologia "G. Colonnetti" (IMGC-CNR)

Torino - ITALY

Abstract

The IMGC-CNR recently acquired two new dead-weight Primary Force Standards, of 30 kN and 1 MN capacity, in addition to those already existing at the IMGC to meet the increasing demand from several industrial sectors in Italy for research and calibration work concerning force sensors and load cells to be used for weighing.

In the present paper the IMGC Primary Force Standards are shortly described and the increase of the dissemination of the Force Unit in Italy, on the basis of the number of the accreditation and certificates issued, is given. The main results of the metrological evaluation and long term stability of the calibration lever machines of one laboratory of the Italian Calibration Service are discussed.

1. Introduction

In recent years, we have seen a marked increase in the demand for force measurements, for an extension of measurement ranges and for a reduction in uncertainty levels, which has brought about a continual improvement in primary and secondary standards.

In conformity with Italian Law 273/91, IMGC provides for traceability to the standards of mechanical and thermal quantities all over the country, so as to allow high-quality measurements and tests to be made.

Each improvement of primary standards and force-transfer standards contributes to improving the entire hierarchical system to disseminate the force quantity, and is translated into greater reliability of the whole industrial production.

To fulfil to this increasing demand from several industrial sectors for calibration and for research on force sensors and load cells for weighing, IMGC has recently acquired two new primary force standards of 30kN and 1MN, in addition to those already in the Institute /1,2/.

The present paper describes the Force National Calibration System and the high increasing of the Calibration Activity in Italy (number of laboratories and certificate issues), presents, as example, the main results of the accreditation, and gives the long term verification, over three years, of the calibration machines of a Laboratory of the Italian National Calibration Service.

In particular a regression analysis was applied to evaluate the metrological characteristics of a Lever Multiplication Machine of 600kN, that are necessary in the field up to 6000 metrical divisions.

2. IMGC Dead-weight Force Standard Machines

The two new primary force standards, of 30kN and 1MN capacity, recently installed at the IMGC, were constructed by C. Galdabini Spa; their design and metrological characterisation were determined in co-operation with IMGC. The latest internationally adopted construction criteria were used in the design and development of these machines.

The main innovative characteristics introduced in the two new machines are:

- weight pieces of AISI 304 austenitic stainless steel
- supporting structure and loading frame of the three-column type, to ensure high rigidity along the different axes
- binary weight-piece combination

- individual suspension and transfer of the weight pieces
- the weight of the loading-frame and of the load-transmission system is balanced by means of a lever system.

The great advantage of the two combined methods (binary with load maintenance) lies in the possibility of self-calibration of the weight pieces, which can be calibrated directly on the machine with uncertainty below 3×10^{-6}, by comparison with one previously calibrated reference weight piece: the load substitution procedure is similar to the procedure proposed by Shoonover for comparison of large masses. Self-calibration additionally allows the force generated by the different weight pieces to be compared directly at the reference dynamometer level.

3. The dissemination oF the force unit

In recent years we have been observed a noticeable increase in the demand for force measurements, for the extension of measurement ranges and for a reduction of measurement uncertainty: in other words, for an improvement of primary and secondary standards [3].

The increasing demand, in Italy in particular, for calibration and certification work and for the accreditation of new calibration centres, is due to a number of concomitant factors, namely:

the need for industry to operate in accordance with EN 45000 and ISO 9000 as regards quality; Italian law 273/91 establishing the National

Calibration System, which comprises the Primary Metrological Institutes and the SIT centres. At present the number of SIT centres is

135 in total, plus 23 for force quantity (load cell, testing machines, impact pendulum and torque).
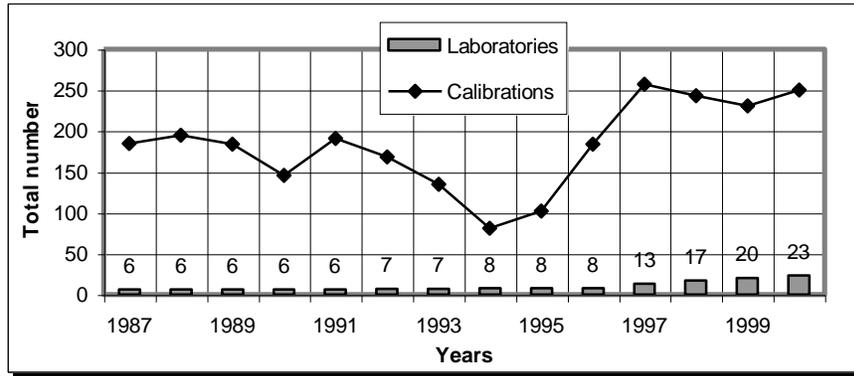

Figure 1. Evolution of the dissemination activities in the force field at IMGC

Table 1. SIT calibration certificates issued in the force field

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Testing machines	499	852	1023	1087	1200	1350	1520	1670	1770
Impact machines	27	47	68	67	75	83	95	104	115
Extensometers	153	175	171	220	230	240	250	260	270
Load cells	53	183	228	260	270	280	320	420	550
Torsiometers		120	200	420	550	650	850	900	950
Total	632	1377	1690	2022	2195	2503	3035	3354	3655

Figure 1 shows the evolution of the dissemination activities in the force field at IMGC and of the number of Calibration Centres accredited by the SIT (with an improvement of about 300% in 10 years). Table I, lastly, gives the number of SIT Calibration Certificates issued in the force field.

4. Metrological Evaluation of Force Calibration Machines

In the following the results of measurements performed, to evaluate the best measurement capabilities of a Force Calibration Centre over 3 years (1997-1999), are considered.

The SIT Centre of the Cooperativa Bilanciai spa (CB), is equipped with three Force Calibration Machines produced by CB.

- Dead weight machine for loads up to 10 kN
- Dead weight machine for loads up to 12 kN connected to the lever multiplication machine,
- Lever multiplication machine (LMC) for loads up to 600 kN with a 1to 50 lever ratio.

4.1. Test Methods and Instrumentation

The contribution of uncertainty associated with the calibration force standards was checked by comparing the results obtained with different dynamometers on the IMGC's primary force standards of 30 kN and 1 MN and on the 12 kN MCF and 600 kN LMC belonging to CB.

The test method was of the same type as that adopted in international comparisons: using several dynamometers for checking from 10% of the scale to the full-scale of the machines. This method consists in calibrating one dynamometer on one of the two machines, a subsequent calibration on the other machine and lastly re-checking the calibration on the first machine, following the scheme A-B-A./4-8/

Four precision dynamometers were used to perform the tests on the LMC:

1. HBM type Z3H3, for loads up to 50 kN
2. HBM type C4, for loads up to 100 kN
3. AEP type Kal-1624, for loads up to 250 kN
4. Revere type C3-SC, for loads up to 600 kN

The output signal was detected with an HBM digital indicators type DMP 39, and DK38S6,

From the comparison of the results obtained with different types of dynamometers it is possible to take into account the numerous parameters in the transmission of the force vector, that provides an integral view of the behaviour of the first-line standard machines of the CB Calibration Centre.

5. Experimental Results and Analysis

5.1. 12kN Dead-Weight Machine

The 12kN CB machine is a dead-weight machine, the nominal values of the forces generated by the masses were determined by direct weighing, taking into account the value of the acceleration of local gravity and the aerostatic thrust. The masses are controlled over time by the Cooperativa Bilanciai using a mass comparator of the Shoonover type with uncertainty of 1,5 ppm.

The verification done in June 1999 thus only involved controlling the effects of transferring the force to the load cell and thus the effects due to the geometric irregularities and deformations of the loading frame. These effects are evaluated by quantifying the rotation effect and the repeatability of the machine.

In the light of the metrological characteristics found during the comparison, which have confirmed the correct functioning and the results obtained during the first control of the machine in 1992, the CB 12kN dead-weight machine is suitable to operate in accordance with the standard OIML R60 and with the standard UNI-EN 10002/3 for class 00, with an uncertainty of 0,005%.
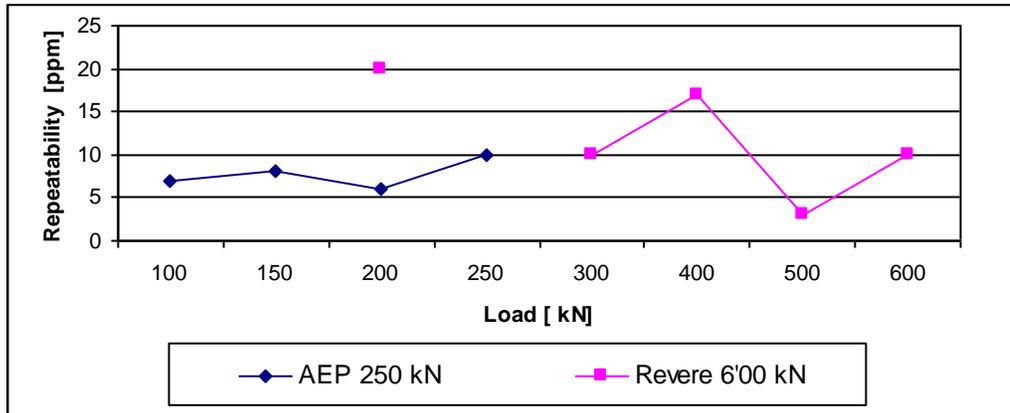
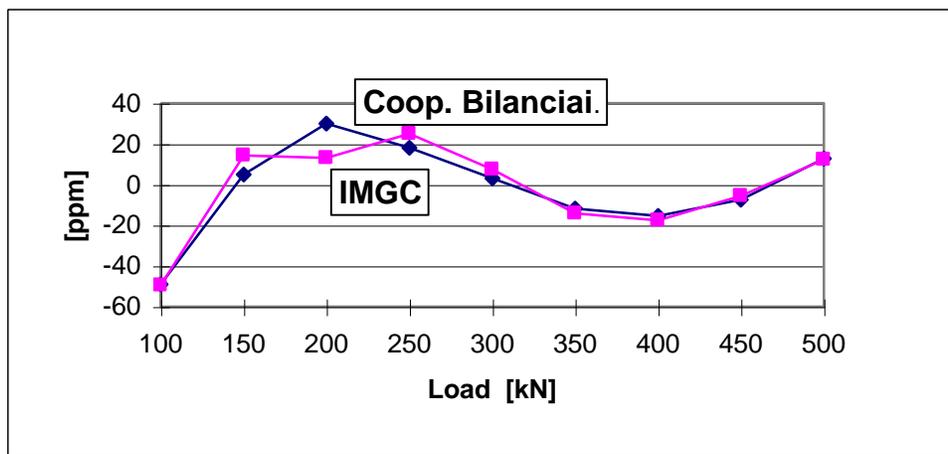**Figure 2.** Repeatability on the Coop. Bilanciai 600 kN lever machine

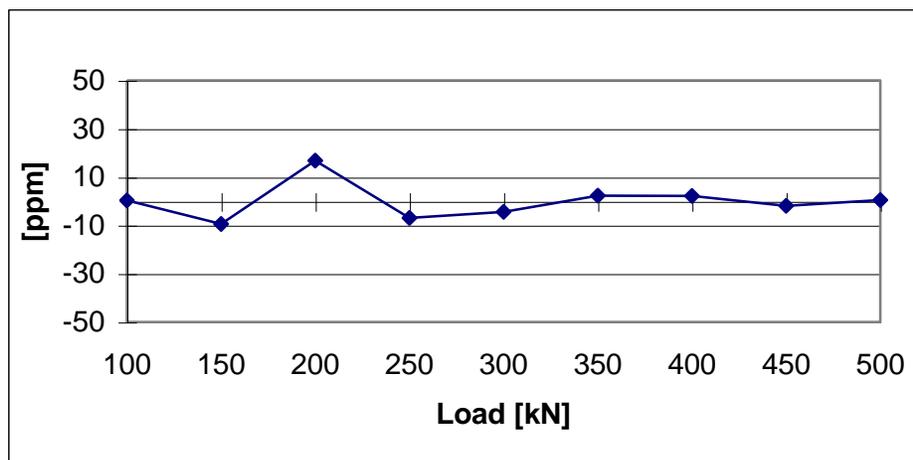**Figure 3.** Residuals of the 2nd order regression

Figure 4. Linearity of the Coop Bilanciai 600 kN lever multiplication machine
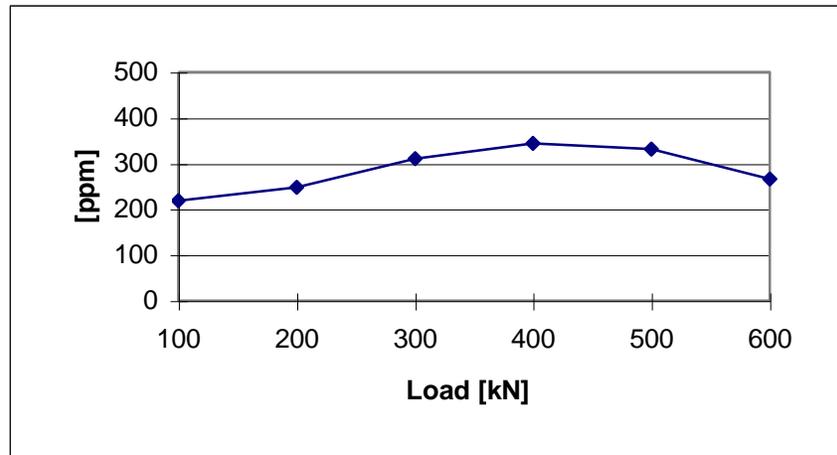
Figure 5. Average of relative deviation between Coop. Bilanciai and IMGC-CNR machines
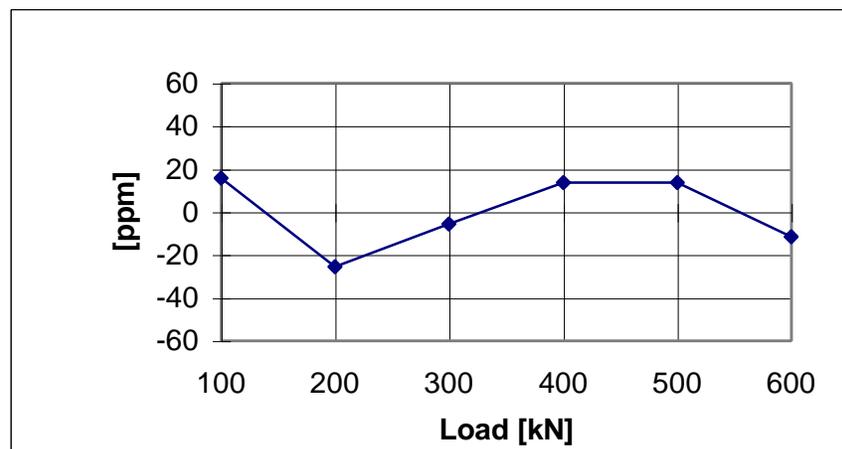

Figure 6. Regression residuals from the average

5.2. The 600kN Lever Multiplication Machine

5.2 1 Metrological Characteristics of the Lever Multiplication Machine

From 1997 to July 1999 systematic tests were done on the 600 kN lever multiplication machine, suited to evaluate the metrological characteristics and the stability over time of the machine.

In particular, it was decided to analyse in depth:

a) the repeatability, rotation effect, hysteresis, non-linearity

b) the transmission ratio from 100 kN to 600 kN, or the characteristic equation of the machine.

Given the construction type of the lever machine, the hysteresis of the machine is inherently stable (in the limits required by the

reference standard), whereas the characteristic of linearity may be evaluated within the transmission ratio (or the characteristic equation of the machine).

The repeatability from 100 kN to 600 kN in ppm, was determined using two load cells of different construction types (AEP-250 kN spokes type and Revere-600 kN column type) (Fig. II) The results confirm those found in March 1998. They indicate that: a) the non-repeatability is small in the whole sample examined (< 20 ppm), independently of the type and the full-scale capacity of the reference transducer cell used; b) there are no significant differences with regard to the repeatability compared to the IMGC primary standard.

Rotation effect: The comparison of the values of rotation effect of the lever machine MCF600, with those determined on the IMGC 1MN force standard machines (typically 60 ppm) confirm the results obtained during the accreditation operations done in 1992 and thus the good reproducibility of the LCM 600kN machine.

With regard the hysteresis, this was compared with that determined on two IMGC-CNR dead-weight standards, so as to eliminate the effect of the reference transducer. Associating a probability distribution to the difference found, as suggested by document EA–4/02, the associated uncertainty was found in all cases to be below 20 ppm.

The non-linearity, determined as the difference in deviation from the regression for the lever machine MCF600 and the dead-weight machine MCF1000, was found to be below 20 ppm.(Figg 3,4)

The regression, calculated from 100 kN to 600 kN, of the relative deviation to the primary national standard (Fig. 5), provided the following equation:

$$C = 105.646 + 1.111422\ F - 0.00137\ F^2$$

where C is the correction in ppm to be applied to the nominal force F, expressed in kN, generated by the MCF 600 machine.

This equation represents the *characteristic equation* of the machine.

The regression residuals, that is the differences between the experimental data and the values calculated with this equation, typically have a deviation below 20 ppm (Fig. 6).

5.2.2. Evaluation of the stability of the main characteristics of the lever machine.

To evaluate the stability of the functional characteristics of the MCF-600 kN machine lever system, the results obtained over the last three years were compared (97-98-99), evaluating the relative differences found compared to the IMGC's MCF 1000 primary standard.

Tab. II summarizes the results obtained with the AEP-250kN dynamometer on the machine in 1997 and 1999. The relative differences (in ppm)

between the two calibrations, and the rotation effect are also given.

Tab. III gives a synthesis of the average results obtained on the IMGC-MCF1000 and CB-LCM machines, with three different dynamometers (HBM, AEP, Revere) from 1997 to 1999.

Columns 4 and 6 report the differences (in 10^{-5}) found between the two successive calibrations.

All these results confirm an excellent stability of the machine-dynamometer system, generally in the order of some parts per 10^5.

Figure 7 gives an overall view of the relative deviation (in ppm) found between the CB lever machine and the IMGC primary dead-weight standard using three different dynamometers from 1997 to 1999. Column 5 reports the average value, determined over three years (Δ), while column 6 gives the $\Delta 99$ deviation from the average value ($\Delta 99 - \Delta$). These results are typically below 20 ppm.
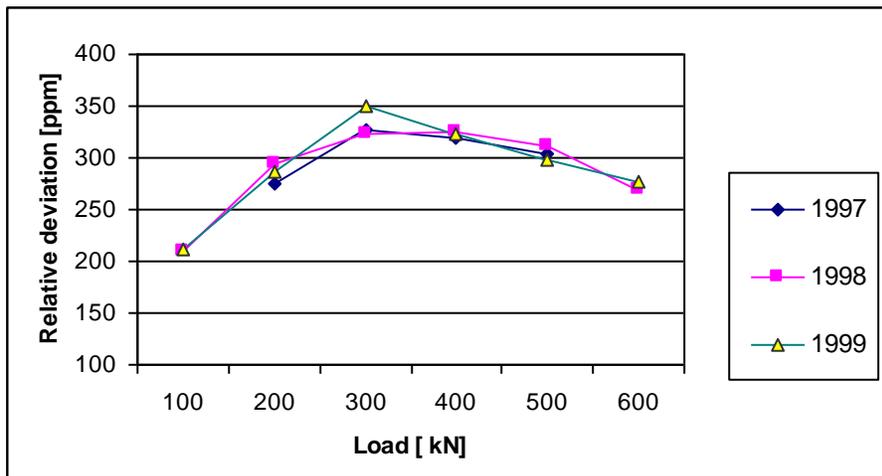
Figure 7. Relative deviation between Coop. Bilanciai and IMGC-CNR standard machines

Table 2. Stability and rotation effect on CB 600kN with AEP 250 kN load cell

[kN]	1999 [digit]	1997 [digit]	$\Delta(99\text{-}97)$ [digit]	Δ with rotation [ppm]
100	800030	800034	- 4	45
150	1200183	1200171	+ 12	80
200	1600316	—	—	80
250	2000408	2000402	+ 6	80

Table 3. IMGC-CNR 1 MN dead weight standard machine

[kN]	1997	1998	Δ (1998-1997) [10^{-5}]	1999	Δ (99-98) [10^{-5}]
100		339900		339899	
200	679803	679787*	- 2,2	679782	-0,8
250					
300	1019729	1019728	- 0,1	1019700	- 2,9
400	1359738	1359728	- 0,7	1359701	- 2
500	1699724	1699710*	- 0,8	1699690	- 1,2
600		2039639		2039618	- 1

Cooperativa Bilanciai 600 kN Lever multiplication machine

[kN]	1997	1998	Δ (1998-1997) [10^{-5}]	1999	Δ (99-98) [10^{-5}]
100	339997	399996		339999	+ 0,5
200	679989	679987	- 0,3	679982	- 0,7
250					
300	1020063	1020058	- 0,4	1020047	- 1
400	1360172	1360170	- 0,2	1360142	- 2
500	1700241	1700240	- 0,07	1700197	- 2,5
600	2040211*	2040190	- 1	2040183	- 0,35

* fitted values

The use of force transducers of different types, capacities and construction rationales (column or spokes) and the use of different test methodologies (4 or 6 cycles) and of different amplifiers (HBM DK38 and HBM DMP 39) points up the significance of the results obtained on the lever multiplication machines, whose stability may be said to be confirmed within some parts per 10^5.

For the evaluation of the best measurement capability, the uncertainty values determined during the comparison, are markedly lower than the uncertainty required for calibration of load cells under the standard ASTM E74-95 and UNI-EN 10002/3, for all values of force generated, considering both the contributions to uncertainty deriving from relative variation between the CB and IMGC machines, and those due to repeatability and the rotation effect .

5. Conclusions

The results obtained during the periodic annual control over three years appear to show an excellent stability of the metrological characteristics of the Cooperativa Bilanciai MCF 600 LCM, and in particular of the functional characteristics of the lever system (transmission ratio), in accordance with the requirements of the reference standards. The machine's characteristic equation from 100 kN to 600 kN is thus: $C = 105.646 + 1.111422\ F - 0.00137\ F^2$

The regression residuals, that is the differences between the experimental results and the values

calculated with the above equation, show a typical deviation below 20 ppm.

The MCF600 lever multiplication machine can operate in accordance with standard OIML R60 in the interval of measurement from 100 kN to 600 kN.

The machine is suitable to operate for the best classes provided for in the standards UNI-EN 10002/3, ASTM 74 and ISO 376 from 20kN to 600kN.

6. References

[1]. Ferrero C., Marinari C., Martino E., *Force Metrology in Italy: the new 1 MN force standard.* XVI IMEKO TC3, Korea 1998, 127-135

[2].Ferrero C., *IMGC fra ricerca, disseminazione ed accreditamento*, Convegno "I Laboratori di prova ", Univ. di Brescia, 1996

[3].Ferrero C., Marinari C., Origlia C., *The dissemination of the Force in Italy,* XVI IMEKO Wien, 2000, 39-44

[4]. Ferrero C., *The measurement of parasitic components in national force standard machines*, Measurement, 8, 1990

[5]. Ferrero C., Marinari C*., Metrological evaluation of load cells to be used as transfer standards*, XXV AIAS, Lecce, 1996

[6].Ferrero, C., Marinari, C., Li Qing Zhong, *The influence of load transfer systems on a force standard machine*, ICEM, Beijing, 1985, pp. 425-433.

[7]. Ferrero C., Marinari C., Gosset A., Averlant P., *Inter-comparison between the LNE and the IMGC force standard machines*, Proc. 15 IMEKO TC-3, Madrid, 1996, pp. 35-41.

[8]. Ferrero, C., Li Qing Zhong, *International comparison of axial load in deadweight force standard machines*, Proc. XII IMEKO Conf., Beijing, 1991, pp. 172-177.

Contact person for paper:

Dr. C. Ferrero
Istituto di Metrologia G. Colonnetti, Strada delle Cacce 73, 10135, Torino, Italia
Phone:+390113977352; Fax: +390113977503;
E-mail: c.ferrero@imgc.to.cnr.it