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THE DISSEMINATION OF THE FORCE UNIT IN ITALY

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Abstract. The establishment of national calibration services (NCS) and mutual agreements between the NCS of the different countries (UKAS, DKD, SIT, etc.) have increased the necessity of the dissemination of the unit of force inside the individual countries and of standards harmonisation through continuous international comparison.

In the paper the new primary standards of 30 kN and 1 MN of the CNR-IMGC are described. Results are given concerning: the evaluation of the internal coherence of the machine; the internal comparison in the laboratory; the dissemination of the force unit in Italy.

Keywords: force standard, calibration, inter-comparison

1 INTRODUCTION

Any improvement in primary and transfer standards is an improvement in the whole hierarchical system of force measuring devices and is consequently converted into greater reliability in industrial production. Substantial progress in the sector of force standards can be made by reducing the parasitic components as function of various parameters in order to bring the sources of error under control, and take effective remedial steps.

The international comparisons so far carried out between different dead-weight machines (DWM) have showed that, besides the axial component, other parasitic components (transverse forces and moments) are present and that the ratio between components reaches 1:40 depending on the machines tested.

Different type force standard machines generate side forces and moments, which differ as to absolute value and direction; a variation in the output signal of the dynamometer, as a function of its position angle to the machine axis, evidences the presence of parasitic components and the sensitivity of the dynamometer to them.

A number of experts have investigated the causes of such components [1, 2, 3] and have studied the possibility of attenuating their effects.

So far nothing has been said about the significance of the complex interlinking existing between the different factors, such interlinking in turn depending in several parameters (load level, ratio of standard stiffness to load cell stiffness, etc.).

Tests carried out on force standard machines of the more important standards institutes by means of a composite six-component dynamometer [4] also brought to light the necessity of strict control of operation and/or of constraint conditions. In order to both limit and ensure the reproducibility of parasitic components and to reduce the overlapping effect and the relative deviation between the primary force standards, two new DWM (of 30 kN and 1 MN capacity) were developed and acquired to be added to those already existing at the IMGC.

The present paper describes the characteristics of the two new standards and the procedure for weight-piece self calibration together with the relevant results and uncertainties.

Results are given concerning:

1. evaluation of the internal coherence of the machine;
2. internal comparison in the laboratory.

Internal coherence of the machines forces is evaluated by comparing the readings of the force transducers subjected at the same force realised with different weight piece combinations in the machine.

Given the self-calibration capability of the new IMGC dead-weight machines (DWM) of 30 kN and 1 MN the internal coherence was evaluated during calibration procedure. In all cases the relative deviations in relation to the average was less than $3{\cdot}10^{-6}$, showing the full consistency of the two machines.

IMGC internal comparison was realised between the three IMGC-CNR Force Standard Dead-weight Machines of 30 kN, 100 kN and 1 MN capacity.

It was made, in compression, by using force transducers of different capacity and stiffness.

The results of that intercomparison show relative deviation in compression always less than $2{\cdot}10^{-5}$.

Finally paper analyses the calibration results obtained by the IMGC-CNR since 1992 and concerning dynamometers produced by different manufactures and utilised by the Centres of our Material Accreditation Service, as first line standards, in the dissemination of the force unit in Italy in accordance with the Italian law 273/91.

2 THE NEW 30 KN AND 1 MN IMGC-DWM'S

The two new primary force standards, of 30 kN and 1 MN capacity (MCF30, MCF1000), recently installed at the IMGC, were constructed by C. Galdabini spa, in co-operation, as regards their design and metrological characterisation, with the IMGC [5, 6, 7]. The latest constructional criteria were adopted in the design and the development of these IMGC machines.

Some requirements were proved to be particularly relevant:

a) the weight pieces and the suspension system must act along the symmetry axis;
b) the force transmission system must act along the longitudinal axis;
c) the loading system must allow loads to be continuously applied without resetting, with the highest number of load levels and the lowest number of weight pieces;
d) load application must be carried out smoothly and without giving rise to dynamic components.

Other innovative characteristics introduced in the design of the two machines are:

1. a supporting structure and a loading frame of the three-column type, to ensure high stiffness along the different directions;
2. binary weight-piece combination and individual suspension and transfer of the weight pieces.
   2a) The weight pieces are independently supported by the supporting structure and are individually applied to the suspension system. The main advantage of this solution is that the position of the individual weight pieces can be controlled, so that they can be positioned axial-symmetrically, thus reducing the oscillations being generated when the weight pieces are being transferred to the load transmission system.
   2b) With a binary combination, only few weight pieces are necessary to obtain a high number of load levels. Eight pieces can generate 256 load levels. In the IMGC 30 kN machine, the following load combinations were adopted (0.1 - 0.2 – 0.4 – 0.8 – 1.6 – 3.2 – 6.4 – 12.8 – 6.4) kN and it is thus possible to have 0.1 kN steps with a maximum applicable load of 31900 N.
   With the IMGC 1 MN machine, the sequence is the following follows: (10 – 10 – 20 – 40 – 80 – 4x160 – 200) kN. The adoption of the binary combination requires, additionally, load to be kept constant on the dynamometer being calibrated during weight-piece substitution, so as to avoid undesirable effects of signal drift.
   Load is kept constant, to within 5%, by a feedback system exploiting the deformation elasticity of the loading frame.

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 lower than $5{\times}10^{-6}$ by comparison with a previously calibrated weight. In fact the load substitution procedure is similar to the procedure proposed by Shoonover for big masses comparison. In this way calibration can be made far quicker (since the reduced number of weight piece) and self-calibration can be repeated in the course of time, to check the stability of the standard.

As regards the weight pieces subsequently used, self-calibration allows the values of the force generated by the different weight pieces to be compared directly at the level of the reference load cell.

In this way, possible effects due to machine distortion and to magnetic, electrostatic and aerodynamic forces are directly included into the calibration of the weight pieces.

3. balancing of the weight of the loading-frame and of the load-transmission system by means of a lever system.

A limit to calibration capabilities in dead-weight machines is in fact the weight of the loading frame. To overcome this difficulty, in the two IMGC machines was adopted the solution proposed by Weiler and Shuster (PTB, 1986). With the adoption of a balancing lever it is possible to have a 0.1 kN minimum load and, consequently, to make the calibrations, in accordance with the ASTM, ISO, EN Standards, of dynamometers of 1 kN full scale with the 30 kN machine or of 100 kN, with the 1 MN machine.

3 GEOMETRICAL CHARACTERISTICS

The essential geometric conditions are alignment and symmetry with respect to the loading axis and are obtained with precision machining of all parts.

The precision of geometric construction was not sufficient to dispense with weight-balancing adjustment, as the eccentricity of the centre of mass is not only caused by shape irregularity, but also by non-uniform density of the material.

The final checking was carried out with three circular sectors lying at 120° on the peripheral part of the weight pieces, with a view to facilitating the final calibration operation and, at the same time, the identification of their centre of gravity.

The parameters to take under control with the mass calibration are the axiality of the loading frame and the weight balancing adjustment.

To evaluate the weight carrying shaft position and the weight balancing adjustment three displacement transducer are positioned at the bottom of the shaft.

The correction of verticality of the shaft for each load is carried out by three moveable masses properly positioned around the circumference.

Figure 1 shows the metrology and the results obtained on the first mass of 160 kN of the 1 MN machine. The control on the shaft position for all load condition is within few 10^{-2} mm.

Figure 2 gives the displacement of the weight carrying shaft of the 30 kN machine, due to application of individual weights as obtained during its calibrations [6].

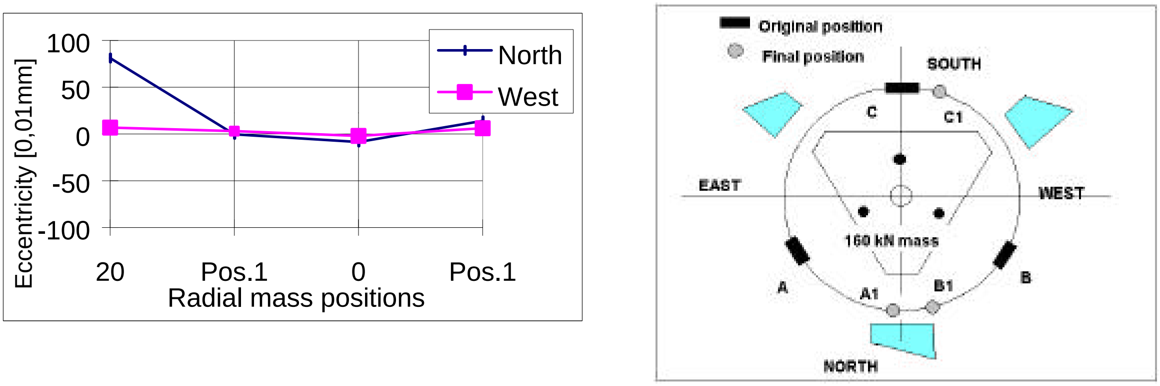

Figure 1. Control of the shaft position on the MCF 1000

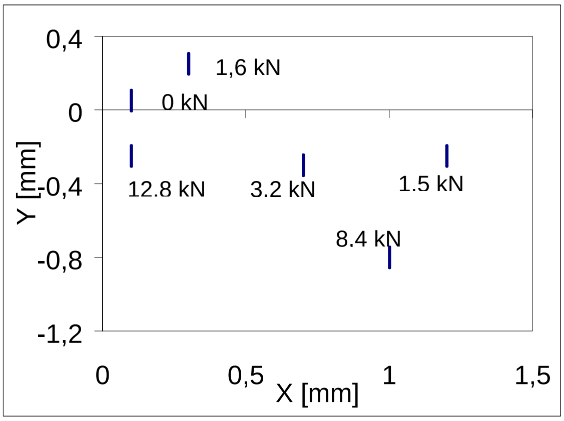

Figure 2. Displacements of the loading frame on the 30 kN DWM

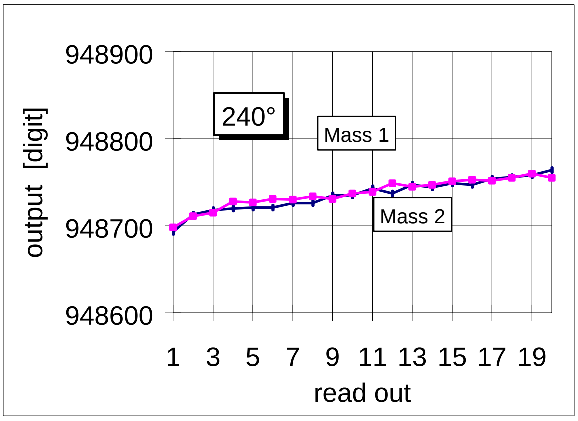

Figure 3. Comparison of two 10 kN reference weights of the 1 MN DWM

4 METROLOGICAL CHARACTERISATION

The uncertainty of the force generated by dead weight standard machine cannot be completely defined in a theoretical way. For this reason a pragmatic approach can be carried out:

1) evaluation of the internal coherence of the machine;
2) internal comparison in the laboratory;
3) inter-comparison with other laboratories.

4.1 Machine internal consistency

Internal coherence of the machine forces is evaluated by comparing the readings of the force transducers subjected at the same force realised with different weight piece combinations in the machine.

Given the self-calibration capability of the new IMGC dead-weight machines (DWM) of 30 kN and 1 MN the internal coherence was evaluated during calibration procedure.

In fact the available standard masses are in binary sequence and, consequently, the possibility to obtain the equivalent load of every mass, by a combination of a smaller mass group, has given the advantage to perform a machine self-calibration program.

The comparison between two weight pieces, A and B, is made in six measurements runs, by rotating, each time, the dynamometer round its longitudinal axis in order to average the effects due to small parasitic components, such as those due to the different centres of gravity of the two pieces.
Each measurement run consist of 20 substitutions, according to the ABAB…AB scheme; the settling time is of 2 minutes.

The program, by comparing the readings on a standard cell with the different mass combinations (the readings are replicated about 200 times), elaborates statistically the difference between the calibrated mass group and the masses under measurement.

Figure 3 gives the resulting differences obtained by using, in order to check both the self-calibration procedure and the calculation programme, the first two reference 10 kN weight pieces of the 1 MN-DWM (nominally identical within few ppm) for one angular positions of the dynamometer.

Processing is based on the calculation of the differences between a datum (An) and the mean of the immediately preceding (Bn) and the successive (Bn+1) data.

Figure 4 gives the differences between the two weight pieces for the six angular positions of the dynamometer with an overall mean value of these differences ($<10^{-6}$).

Figure 5 shows the results obtained on the 30 kN-DWM during the comparison of the first weight of 1,6 kN and the reference package of weights.

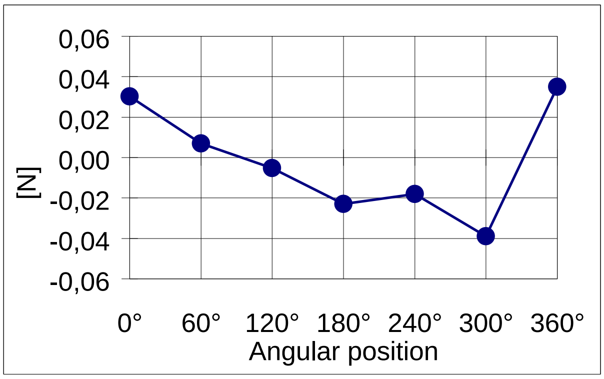

Figure 4. Different between the two weights of 10 kN in the self calibration tests (MCF 1000)

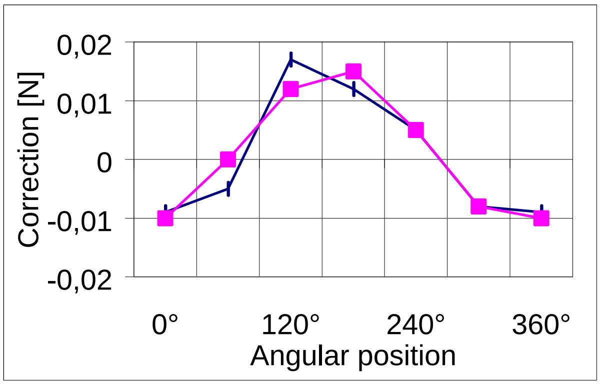

Figure 5. Self calibration results for the first 1,6 kN weight (MCF 30)

4.2 IMGC internal comparison

IMGC internal comparison (point 2) was realised between the three IMGC-CNR Force Standard Machines of 30 kN, 1 MN and 100 kN capacity.
It was made, in compression, by using several force transducers of different capacity and stiffness (HBM Z12 – 50 kN and TMT AOB – 100 kN; AEP - KAL – 50 kN) connected to a HBM DMP 40 amplifier.

The results of the intercomparison between 30 kN and 1 MN DWM, (relative deviation in compression less than $1{\cdot}10^{-5)}$ and the reproducibility obtained on the MCF30 by applying different loading schedule (cycle A: steps of 5 kN; cycle B: steps of 10 kN) are given in Table 1.

Figure 6 gives the relative deviation between MCF 30 and Amsler 105 kN by using three compression load cells (Z3H3-5 kN, Z3H3-10 kN; Z3H3-20 kN).

Table 1. Relative deviation between MCF30 and MCF1000 and the reproducibility on MCF30.

	Relative deviation				**Reproducibility**
LOAD [kN]	HBM Z12 [ppm]	TMT [ppm]	AEP KAL Cycle A	AEP KAL Cycle B	[ppm]
10	8	5	399848	399852	10
20	9.5	7	799760	799762	2.5
30	3.3	6.2	1199730	1199733	2.5

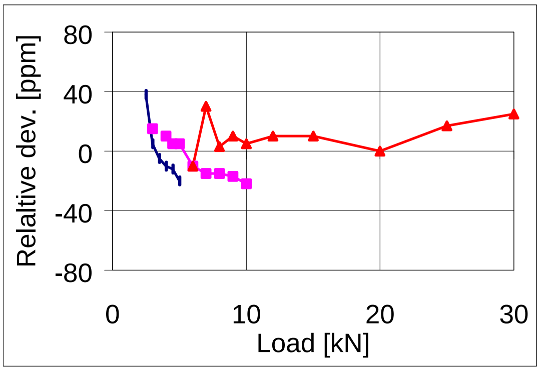

Figure 6. Relative deviation between the MCF30 and the Amsler 105 kN DWM's

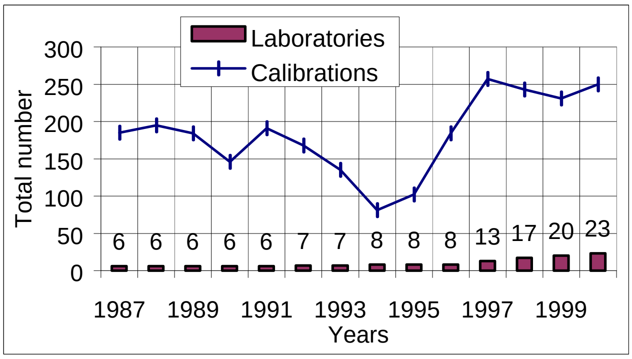

Figure 7. Development of the calibrations and of the SIT laboratories in the last 13 years

5 THE DISSEMINATION OR THE UNIT OF FORCE

In recent years we have been witnessing a noticeable increase in the demand for force measurements, for the extension of measurement ranges and for measurement uncertainty reduction: in other words, for an improvements of primary and of secondary standards [8].

The increasing demand, in Italy in particular, for calibration and certification work and for the accreditation of new calibration centres due to a number of concomitant factors, namely:
the necessity, for industrial concerns, to operate in accordance with EN 45000 and ISO 9000 as to quality; the Italian law 273/91 establishing the National Calibration System (Sistema Nazionale di Taratura), which is constituted by the Primary Metrological Institutes and by the centres of SIT, the Calibration Service in Italy (actually 125 in total, 20 for force).

Table 2. Number of first line standards calibrated in IMGC-CNR for SIT and University laboratories

	First line standard					
	S.I.T. calibration Laboratories			University calibration Laboratories		
Measur. range	Compression	Tension	Comp./ Tens.	Compression	Tension	Comp./ Tens.
10 N - 500 N	7	4	13			2
500 N - 2,5 kN	3	2	16	3		1
2,5 kN - 20 kN	6	3	20	5		2
20 kN - 100 kN	6	13	20	8		4
100 kN - 1 MN	30	12	10	23	1	6
1 MN - 3 MN	11			11		
3 MN - 9 MN	6			11		

In accordance with the italian law 273/91, the IMGC-CNR provides for traceability to the standards of mechanical and thermal quantities, thus allowing high-quality measurements and tests to be made.

Figure 7 shows the evolution of the dissemination activities in the force field at IMGC and of the number of Calibration Centres accredited by the SIT (about 300% in 10 years).

Table 2 gives the number of first line standards calibrated at IMGC for the SIT and University Calibration Centres. The different measuring ranges are reported.

Finally table 3 gives the number of the SIT Calibration Certificates, in the force field.

Table 3. SIT calibration certificates in force field

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

6 CONCLUSIONS

Self-calibration of the 1 MN standard machine made it possible to verify the inner consistency of the weight pieces within some parts in 10^6. The expanded uncertainty in force measurements can be said to be lower than $2 \cdot 10^{-5}$ over the whole measurement range of the standard.

A new figure for the expanded uncertainty of the force generated by the standard machines can be obtained only with external inter-comparisons.

Several inter-comparisons are in program of force standard between primary metrology institutes, within EUROMET and CCM (Key-comparisons).

The IMGC 30 kN and 1 MN standards were included in the Calibration Service in Italy in the second half of 1998, to meet the strong increasing of calibration, certification and accreditation demands from the industry.

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