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Dissemination of the force unit in Italy: intercomparison results up to 20 kN

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Abstract

In the field of calibration, Italy participates to the European framework with SIT(Servizio di Taratura in Italia), which grants accreditation through the verification of the correctness of the calibration of the measurement instruments with reference to the National Standards maintained by the Metrological Institutes INRIM and ENEA.

One of the most important activities of the National Accreditation Body (NAB) is the organisation of a series of interlaboratory comparisons (ILC), at European (EA) and National level, to verify the measurements capability of the accredited laboratories.

In 2004 and In January-February 2005 ILCs, for the calibration of force transducers, were organised in Italy by the SIT with the INRiM (formerly IMGC-CNR and IEN) as pilot laboratory. At the experimental ILCs participated four accredited Calibration Laboratories. The relative deviation up to 20 kN of the calibration machines, from the INRIM standard deadweigh machines (DWM), were allways less than +/- 50 $10^{-6.}$

Keywords: load cell, transfer standard, intercomparison

1) Introduction

The Italian law 273/91 establishing the National Calibration System, which is constituted by the Primary Metrological Institutes (Istituto Nazionale di Ricerca Metrologica (INRiM) and ENEA) and by the accredited Laboratories of the SIT, the calibration service in Italy (actually 174 in total, 21 for force.

In accordance with the law 273/91, the INRiM provides for traceability in Italy to the standards of mechanical, thermal, chemical and electrical quantities, thus allowing high-quality measurements and tests to be made.

In 2004 and in January-February 2005 ILCs, for the calibration of force transducers, was organised in Italy by SIT with the INRiM (formerly IMGC-CNR and IEN) as pilot laboratory. At the experimental ILC participated four accredited Calibration Laboratories.

The results of participating laboratories were evaluated against calibration results from pilot laboratory. To establish the reference values it has been used force transducers, with nominal values from 500 N to 20 kN. These transducers have a long well known metrological history and the capability of transducers is also well known.

The uncertainty associated with calibration force standard machines was checked by comparing the results obtained with different dynamometers on the INRiM primary force standards from 2 kN to 30 kN dead weight machine.
In the present paper the main results obtained during the ILC are discussed, in particular the differences on the repeatability and accuracy given by the different calibration laboratories are compared and evaluated.

The results were evaluated using the normalized error En according to the ISO Guide 43.

For the evaluation of the best measurement capability, we can say that the uncertainty values determined during the comparison, are markedly lower than the uncertainty required for calibration of load cells under the standard UNI-EN ISO 376, for all values of force generated, considering both the contributions to uncertainty deriving from relative variation between the laboratories and INRiM machines, and those due to repeatability and the rotation effect.

2. Metrological evaluation of Force Calibration Machines

2.1 Force calibration machines of participating institutions

A total of four accredited laboratories participated in intercomparison. The force calibration machines capacities involved in the ILC are as follows: COOPBIL (one of 1 kN and one of 12 kN), AEP (one of 2 kN, and one of 50 kN), Galdabini (one of 2kN), TMT (one of 5 kN-DWM and one 100 kN CM). The pilot machines in the intercomparison are the INRIM 2 kN manual machine and the 30 kN and 1 MN Galdabini force standard machines.

2.2 Measurement equipment

The seven load cells used as reference force standards are from 500 N to 50 kN in capacity, compression type. Load cells are of different manufacturers and different elastic body structures. The model and serial numbers of the seven compression load cells used in the comparative tests were: RPO-Ba3-500 N; RPO-Ba3-1 kN; RPO-Ba3-5 kN; RPO-Ba3-10 kN; HBM-TOP-2 kN; HBM-TOP-20 kN; AEP-KAL-50KN.

For data recording were used three HBM DMP40 digital precision measuring unit. The DMP40 settings were: excitation voltage: 5 V; unit: mV/V; range 2,5; Low-pass filter: 0,10Hz Be.

2.3 Measurement procedure

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 different DWM. 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 to evaluate stability (drift) of the transfer transducer, following the scheme A-B-A.

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 calibration machines of the accredited Laboratories.

The calibration was realised in 4 angular positions (0°, 0°, 90°, 180°, 270°) and repeated two times in the same angular position to evaluate the repeatability.

3. Measurement results

In the following the results of measurements performed over 2 years (2004-2005) during the renew of accreditation, to evaluate the best measurement capabilities of the force accredited calibration Laboratories, are considered

3.1 Long-term stability of reference load cells

The long term stability of transfer standards sensitivity was measured on the INRIM DWMs once a month over a period of four months.Table 1 gives an example of the results for the RPO-BA3 5 kN transfer standard.

Table 1 - LONG TERM STABILITY Load Cell RPO-BA3 5 kN

FORCE	INRIM Average	Differences	on INRIM	DWM		
N	mV/V	ppm				
500	0,203401	6	6	-5	-4	-5
1000	0,406816	8	6	-7	1	-7
1500	0,610239	9	8	-10	2	-9
2000	0,813666	10	7	-11	2	-9
2500	1,017105	13	5	-10	1	-9
3000	1,220552	13	3	-8	1	-9
3500	1,424009	11	4	-5	0	-10
4000	1,627474	8	5	-3	-1	-9
4500	1,830946	5	5	-2	1	-9
5000	2,034426	1	5	-1	0	-6

For the transfer standards used in the ILC, the long-term variation of sensitivities were, as a rule, inside ± 30 ppm.

3.2 Short-term instability of reference load cells

The short-term variation of the sensitivity of force transducers can be separated from the data for long-term stability previously described. Table 2 shows, as an example, the results for the short-term stability of the RPO-Ba3-1 kN transfer standard.

Table 2 – Short term stability for the load Cell RPO-BA3 1 kN

Force	Measure 22/02/2005	Measure 24/02/2005	Short Term Stability
N	mV/V	mV/V	ppm
200	0,402633	0,402634	-3,0
300	0,603960	0,603961	-2,3
400	0,805302	0,805297	6,1
500	1,006645	1,006647	-2,2
600	1,208002	1,207999	2,0
700	1,409367	1,409357	6,8
800	1,610731	1,610725	3,7
900	1,812101	1,812099	1,5
1000	2,013469	2,013470	-0,4

4. Test results

4.1 Test results on the AEP Calibration Machines

a) Figure 1 shows the relative differences (AEP- INRIM /INRIM). obtained with dynamometers type RPO-BA3-5 kN and AEP-KAL-50 kN, between the INRIM Primary standards machines of 1 MN and 30 kN and of the 50 kN AEP MCF calibration dead weight machine.
Typically, these differences are below 30 ppm.

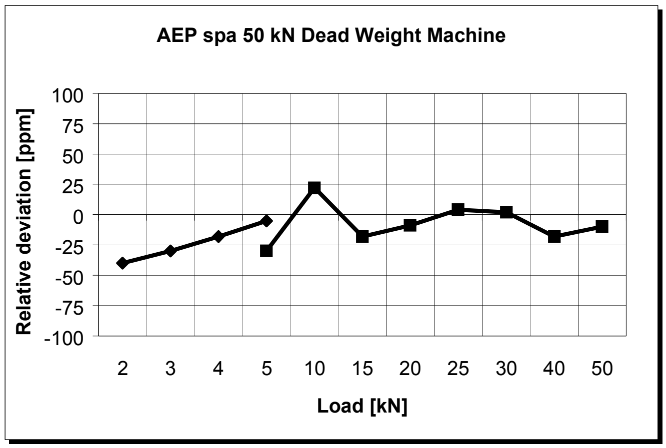


Figure 1 - Relative differences between the AEP and INRIM DWMs.

The figure report the mean values calculated over four angular positions of the dynamometer, carefully verifying the position of the dynamometer each time in relation to the axis of the machine so as to check the rotation effect more precisely and thus the existence of any transverse or eccentric components.

The rotation effect were found to be below 50 ppm for the 50 kN dead weight machine, acceptable for this type of Force Calibration Machine and for the load cells used.

The evaluation of the rotation effect was made by comparison with the analogous effect measured on the INRIM standard machine: typically of the order of 40 ppm. Repeatability was of the order of 1 10^{-5} at full scale and certainly within 2 10^{-5} for the part under verification.

b) Table 3 shows the relative differences, obtained with dynamometer type HBM TOP-Z30/2kN, between the 2 kN INRIM manual primary standards and the 2 kN semi-manual AEP calibration machine.
Typically, these differences are below 30 ppm.

Table 3: relative deviation between AEP calibration machine and the 2 kN INRIM primary standards

FORCE	INRIM-man.	AEP	AEP-INRIM
N	mV/V	mV/V	ppm
200	0,200058	0,200060	9
400	0,400118	0,400124	15
600	0,600169	0,600179	17
800	0,800228	0,800240	15
1000	1,000292	1,000306	14
1200	1,200359	1,200380	17
1400	1,400424	1,400458	24
1600	1,600496	1,600535	24
1800	1,800569	1,800610	23
2000	2,000647	2,000690	21

4.2 Test results on the COOPBIL Calibration Machines

For these dead-weight calibration machines, the nominal value of the forces generated by the masses are 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 (COOPBIL) using a mass comparator of the Shoonover type with uncertainty of 1,5 ppm.

The verification done in 2004-2005 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.
The main results, may be summed up as follows:

a) 12 kN MCF02 calibration dead-weight machine.

Tables 4 and 5 show the relative differences (COOPBIL- INRIM /INRIM). obtained with the dynamometer types RPO-BA3-10kN and HBM-TOP Z4A-20KN, between the INRIM Primary standards machines of 30 kN and the 12 kN COOPBIL dead weight machine.

Typically, these differences are below 30 ppm for both the transfer standards.

In Table 4 are also reported the first (D1) and second (D2) order differences between the force steps on the INRIM and COOPBIL DWMs. In particular the columns D2 is an indication that the differences of the increasing masses are of the order of a few parts in 10^{-6}.

The total results confirm those found in March 1998. They indicate that: a) the non-repeatability is small ($<2x10^{-5}$), in the whole sample examined, 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.

The rotation effect is of the order of $\pm 5x10^{-5}$ for HBM-Top-20kN load cell and of $\pm 10x10^{-5}$ for RPO-10kN. The differences with the results obtained on the INRIM primary DWM are always less than $\pm$ $5x10^{-5}$.

Table 4: Relative deviation with the RPO-BA3-10 kN transfer standard

Force	IMGC 17/01/2005	COOPBIL 02/02/2005	D1 IMGC	D2 IMGC	D1 COOPBIL	D2 COOPBIL	CB-IMGC
[kN]	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	ppm
1	0,202205	0,202210			0,202210		27
2	0,404412	0,404423	0,202208		0,202213	0,000003	26
3	0,606620	0,606640	0,202208	0,000001	0,202218	0,000005	33
4	0,808837	0,808862	0,202216	0,000008	0,202221	0,000003	31
5	1,011059	1,011088	0,202223	0,000006	0,202226	0,000005	28
6	1,213278	1,213306	0,202218	-0,000004	0,202218	-0,000008	24
7	1,415488	1,415519	0,202211	-0,000008	0,202213	-0,000005	22
8	1,617701	1,617728	0,202213	0,000002	0,202208	-0,000005	16
9	1,819916	1,819942	0,202215	0,000002	0,202214	0,000006	14
10	2,022142	2,022166	0,202226	0,000011	0,202225	0,000010	12
10kN-3kN	1,415522	1,415526					3,1
10kN-4kN	1,213305	1,213305					-0,3
10kN-5kN	1,011083	1,011078					-4,2

Table 5: Relative deviation with the HBM-Z4A TOP 20kN transfer standard

FORCE	CB	INRIM	CB-INRIM
kN	mV/V	mV/V	ppm
2	0,199837	0,199837	0
4	0,399654	0,399646	20
6	0,599429	0,599415	24
8	0,799168	0,799144	31
10	0,998855	0,998831	24

In the light of the characteristics found during the comparison, we believe that the COOPBIL MCF02-12 kN DWM is suitable to operate in accordance with the standard OIML R60 for load cells from 0,4 kN to 12 kN (up to 6000 metric divisions), in accordance with the standard ISO 376 for class 00 force transducers and in accordance with standard ASTM E74 for class AA force transducers.

b) 2 kN MCF01 calibration dead-weight machine.

Table 6 shows the relative differences, obtained with dynamometers type HBM TOP-Z30/2kN, between the 2 kN INRIM manual primary standards and the 2 kN manual COOPBIL dead weight calibration machine.
Typically, these differences are below 30 ppm.

Table 6: Relative deviation of the 2 kN COOPBIL calibration machine

FORCE	INRIM-man.	COOPBIL	CB-INRIM
N	mV/V	mV/V	ppm
200	0,2000582	0,200057	-7
400	0,4001178	0,400105	-32
600	0,6001688	0,600158	-18
800	0,8002280	0,800217	-14
1000	1,0002924	1,000273	-19
1200	1,2003590	1,200334	-21
1400	1,4004240	1,400403	-15
1600	1,6004964	1,600471	-16
1800	1,8005686	1,800548	-12
2000	2,0006470	2,000624	-11

Repeatability on the 2 kN MCF01Manual DWM is of the order of 1 10^{-5} at full scale and certainly within 2 10^{-5} for the part under verification.

4.3 Test results on the Galdabini (CG) Manual Calibration Machine

Figure 2 shows the relative differences (CG- INRIM /INRIM) between the INRIM standards machines of 2 kN and of the 1 kN CG calibration DWM obtained in 2004, during the accreditation extension, with transfer standards type RPO-Ba3-0,5 kN and RPO-Ba3-1 kN. Typically, these differences are below 30 ppm.

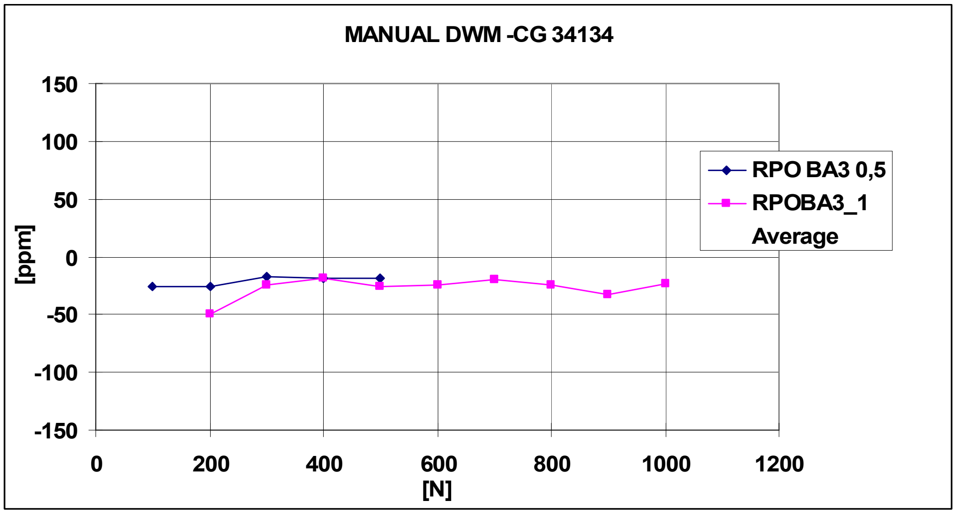


Fig. 2: relative deviation of Galdabini manual calibration machine

Table 7a,b compare the relative differences (CG- INRIM /INRIM) obtained with the dynamometers RPO-BA3-1 kN and HBM-TOP Z4A-0KN, during the renew of accreditation in February 2005, with the results obtained in April 2004 by using the transfer standards type RPO-Ba3-0,5 kN and RPO-Ba3-1 kN.

Table 7a,b

Force [N]	RPO-1kN [ppm]	HBM TOP-2kN [ppm]	Average [ppm]
100	-27		-14
200	-51	-27	-39
300	-25		-25
400	-3	-26	-14
500	-30		-15
600	-25	-15	-20
700	-15		-15
800	-17	-18	-18
900	-31		-31
1000	-19	-14	-17

Force N	RPO BA3 0,5 [ppm]	RPOBA3_1 [ppm]	Average [ppm]
100	-25		-13
200	-25	-50	-37
300	-17	-25	-21
400	-19	-19	-19
500	-18	-26	-22
600		-25	-25
700		-20	-20
800		-25	-25
900		-33	-33
1000		-23	-23

The differences on the average values as determined in 2004 and 2005 with different transfer standards are always less than 10 ppm.

4.3 Results on the TMT Calibration Machines in EA framework

Inside the EA/LC Commission, the Mechanical Measurements Group is responsible to organize interlaboratory comparisons (ILC) and to consider the need for a new technical guides in the following fields: force, hardness, torque, mass and balance, vibration. The EA interlaboratory comparison F3 for FORCE was planned at the end of 1999 and carried out between 2002/03 and 2004/06. The purpose of the EA interlaboratory comparison is as stated in EA-2/03 [1], i.e to verify the competence of accredited laboratories, including verification of the reported measurement uncertainty

The EA interlaboratory comparison F3 was organised by SWEDAC. SP, the Swedish Research and Testing Institute, was appointed as reference laboratory. The number of participant laboratories was limited to two in each country (AEP-IT1 and TMT-IT2 were appointed by the SIT for Italy).

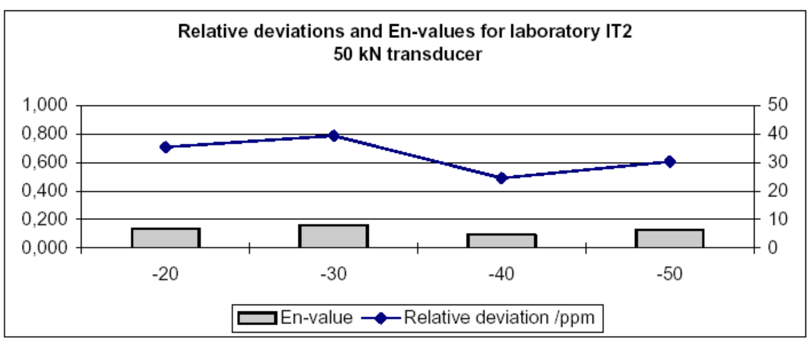
Tables 8a,b give the relative deviation to the pilot reference value evaluated with the HBM-Z3H3 transfer standard, and the normalised error En of the TMT Centre. This value (at F= 20 kN), is in agreement with the general results obtained for the other three SIT calibration centres involved in the national ILC.

Measurement value and expanded uncertainty for 50 kN force transducer
Relative deviations and En-values for laboratory IT2

Table 8a

Nominal force value F /kN	Reference value (mV/V)	Output signal X (mV/V)	Relative deviation /ppm	Uncertainty U (k=2) (mV/V)	Uncertainty U (k=2) (ppm)	CMC table (ppm)	E_n-value
-20	-0,813993	-0,814022	35	0,000195	240	200	0,135
-30	-1,220936	-1,220984	39	0,000293	240	200	0,160
-40	-1,627830	-1,627870	25	0,000391	240	200	0,094
-50	-2,034620	-2,034682	30	0,000468	230	200	0,128

Table 8b



5. Results analysis

On the basis of the test results obtained during the ILC and outlined in previous Figures and tables, the following considerations may be made:

5.1 Side force and moments.

Figures and tables report the mean values calculated over four angular positions of the force transducers, carefully verifying the position of the force transducers each time in relation to the axis of the machine so as to check the rotation effect more precisely and thus the existence of any transverse or eccentric components. In particular:

a) The lateral forces and moments may be considered sufficiently small on the basis of the rotation effect determined with force transducers placed in different angular positions compared to the axis of the machine.

b) As expected, the rotation effect is generally lower for the three-column isostatic structure machine than that obtained for the two-columns machine. Their value is such as not to influence the average output of the single-component dynamometers, and thus the uncertainty of the forces generated by the different calibration machines.

5.2 Uncertainty and normalised error En

For the evaluation of the best measurement capability for the four accredited Calibration Centres, (< 0,01% for the DWM and < 0,02% for comparison machine) 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 ISO 376, for all values of force generated, considering both the contributions to uncertainty deriving from relative variation between the calibration and INRIM machines, and those due the other contributions (repeatability, rotation effect, etc.) as defined in EA/10-04.

The relative deviation of each force calibration machine is expressed, where possible, as the average of the results obtained with different transfer standards for the same force range. The results can be evaluated using the normalised error En according the ISO Guide 43 and EA-2/03 guideline:

$$En = \frac{X_{LAB} - X_0}{\sqrt{U^2_{LAB} + U^2_0}}$$

Where:
X_{LAB}= the calibration result given by the laboratories
X_0 = the reference value
U_{LAB}= the uncertainty reported by the laboratories
U_0 = the uncertainty of the reference value.
The normalised error En is, as a rule, less than 0,3 for all the calibration machines involved in the intercomparison.

6. Conclusions

The expanded uncertainty in force measurements can be said to be lower than $2 \cdot 10^{-5}$ over the whole measurement range of the INRIM primary standards. The metrological procedures applied and the results of the renew of accreditation of a SIT calibration Laboratories, show that the best measurement capabilities and the total uncertainty, including transfer standards contribution and long term stability, can be considered lower than ± 50 ppm.

In the light of the characteristics found during the comparison, the calibration machines are suitable to operate in accordance with the standard ISO 376 for class 00 force transducers and in accordance with standard ASTM E74 for class AA force transducers. The normalised error En is in fact, as a rule, less than 0,3 for all the calibration machines involved in the intercomparison.

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