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A COMPARATIVE VERIFICATION OF FORCE CALIBRATION MACHINES USED BY AN ACCREDITED LABORATORY

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Abstract – One of the most important activities of the National Accreditation Body (NAB) is the organisation of a series of comparisons (ILC), at the National level, to verify the measurements capability of the accredited laboratories

For evaluation of the best measurement capability of AEP Transducers -an calibration accredited laboratory for Force quantity - over several years (1999-2005) are carried out measurements during accreditation and re-accreditation process of this SIT Centre, whose main results are reported in the following.

The results were evaluated using the En - normalised error - according to the SIT Doc-511.

The metrological procedures applied and the results of the accreditation of the SIT Centre, show that the best measurement capabilities and the total uncertainty, including transfer standards contribution and long term stability, can be considered as well:

± 50 ppm for the 50 kN dead weight machine (DWM);
± 250 ppm for the 200 kN Comparison machine;
± 350 ppm for the 1 MN Comparison machine (compression)
± 250 ppm for the 1 MN Comparison machine (tension).

Keywords: force, intercomparison, accreditation

1. INTRODUCTION

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

- the exigency of compliance with the EN Standards in the fields of quality and production;
- the necessity for industrial concerrns, to operate in accordance with EN 45000, ISO 9000 and ISO 17025.
- the Italian law 273/91 establishing the National Calibration System (Sistema Nazionale di Taratura), which is constituted by the Primary Metrological Institutes (Istituto Nazionale di Ricerca Metrologica (INRiM) e l'Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti) and by the centres of SIT, the calibration service in Italy (actually 177 in total, 23 for force.

Measurement of a physical quantity requires the establishment of a metrological chain, the starting point of which is the primary standard of the quantity in question. This standard must be transferable to secondary standards and to work standards having the required metrological characteristics.

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

Any improvement in primary force standards and transfer standards gives a contribution to the whole hierarchy of the Force quantity and is converted into higher reliability of the whole industrial production.

Table 1. Number of SIT Calibration Certificates issued in the force field.

	1999	2000	2001	2002	2003	2004	2005
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	80	120	200	420	550	650	850
Total	712	1377	1690	2022	2195	2503	3035

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

The results of participating laboratories normally are evaluated against calibration results provided by the pilot laboratory. To establish the reference values force transducers are used , with different nominal values. These transducers have a long metrological history and their capability is well known.

The uncertainty associated with calibration force standards was checked by comparing the results obtained with different dynamometers from 1 kN to 1000 kN on the INRiM primary force standards dead weight machine (DWM).

The test method is 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 force standards.

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 standard machines of the SIT Calibration Centres.

2. METROLOGICAL EVALUATION OF FORCE CALIBRATION MACHINES

2.1 Measurement equipment

The five load cells used as reference force standards are from 5 kN to 1000 kN in capacity, compression and tension type. Load cells are of different manufacturers and different elastic body structures. The model and serial numbers of the five load cells used in the comparative tests were: RPO-Ba3-5kN; HBM-TOP-20kN; AEP-KAL-50kN, AEP-KAL-500kN, AEP-KAL-1000kN.

For data recording was used a 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.

For evaluation of the best measurement capability of AEP Transducers -an calibration accredited laboratory for Force quantity - over several years (1999-2005) are carried out measurements during accreditation and re-accreditation process of this SIT Centre, whose results are reported below.

The SIT Centre of the AEP Transducers spa, is equipped with three Force Calibration Machines produced by Galdabini Spa:

- Dead weight machine (MCF) up to 50 kN
- Comparison machine (MTC) up to 200 kN
- Comparison machine (MTC) up to 1000 kN

Under assessment, the Laboratory and its standard machines were transferred to a new location. The results of the metrological verification before and after the transfer are of particular significance since they enable the stability of the metrological characteristics of the standard machine to be evaluated.

2.2 Experimental results

The 50 kN dead weight machine was completely disassembled and reassembled in the new laboratory, while the comparison machines were transported without being disassembled.

The uncertainty of AEP Laboratory associated with calibration force standards was checked by comparing the results obtained with different dynamometers on the INRIM primary force standards from 30 kN to 1 MN.

In the present paper the main results obtained during the comparison are discussed, in particular the differences on the repeatability and accuracy given by the different calibration machines are compared and evaluated.

Before and after transfer of the AEP Force standards, calibration was carried out with different types of dynamometer in order to evaluate the stability of the machine during the operations of transfer and reassembly as shown in the Fig. 1.

Fig. 2 shows the relative differences between the two machines obtained with traction tests with the different dynamometers on the INRIM hydraulic multiplication force standard machine and the AEP 1 MN comparison machine. The figures also show the relative differences of the results obtained in 1997-1998 and those before the transfer in the new laboratory in 1999 (AEP1).

Fig. 3 shows the relative differences between the two machines (AEP- INRIM / INRIM). obtained with dynamometers type RPO-BA3 (5 kN) and AEP-KAL (50 kN) on the 1 MN and 30 kN INRIM primary standards and on the 50 kN AEP MCF dead weight machine.

Typically, these differences are below 30 ppm

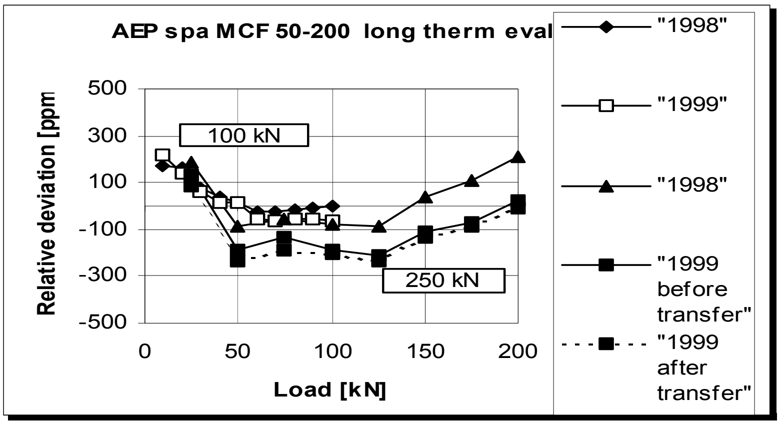

Fig. 1. Relative differences between the AEP comparison machine and INRIM dead weight machines up to 200 kNin compression.

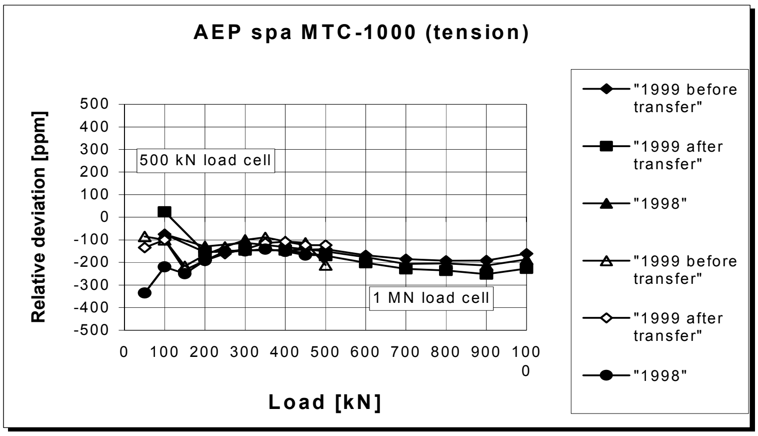

Fig. 2. Relative differences between the AEP comparison machine and INRIM dead weight machines in tension.

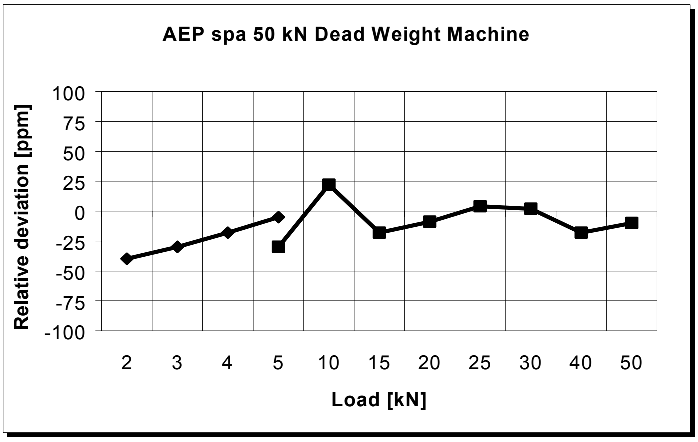

Fig. 3. Relative differences between the AEP-MCF and INRIM-DWM in tension up to 50 kN.

The Fig. 4 reports 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. It shows the relative differences of the results obtained in 1999 and 2005 on the MTC200 and MTC1000 up to 200 kN.

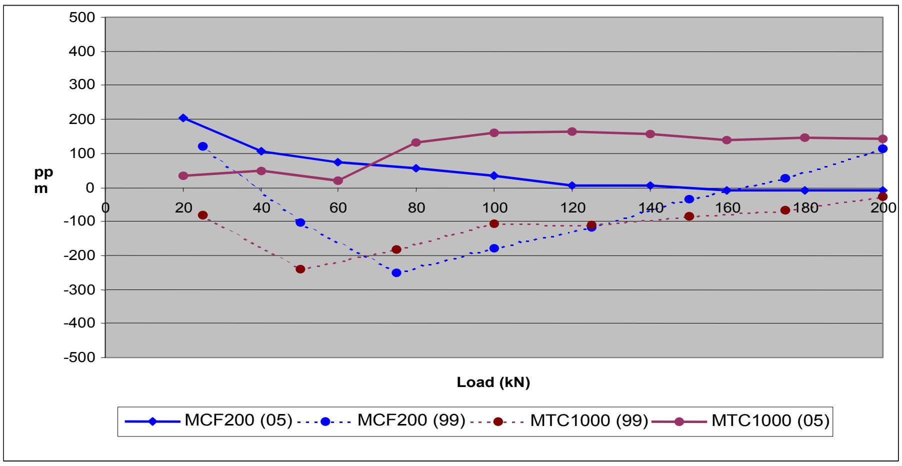

Fig. 4. Long-term data 1999-2005) of MTC AEP machines in compression up to 200 kN.

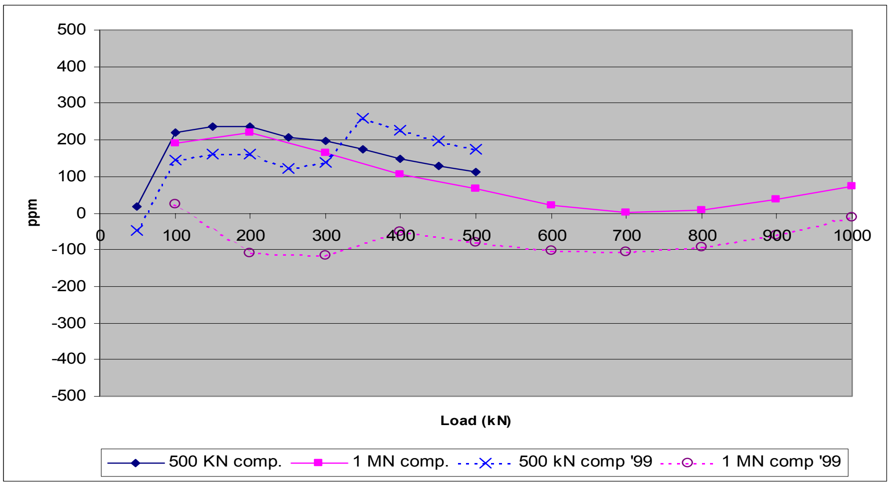

Fig. 5. Long-term data of MTC AEP machines in compression up to 1000 kN.

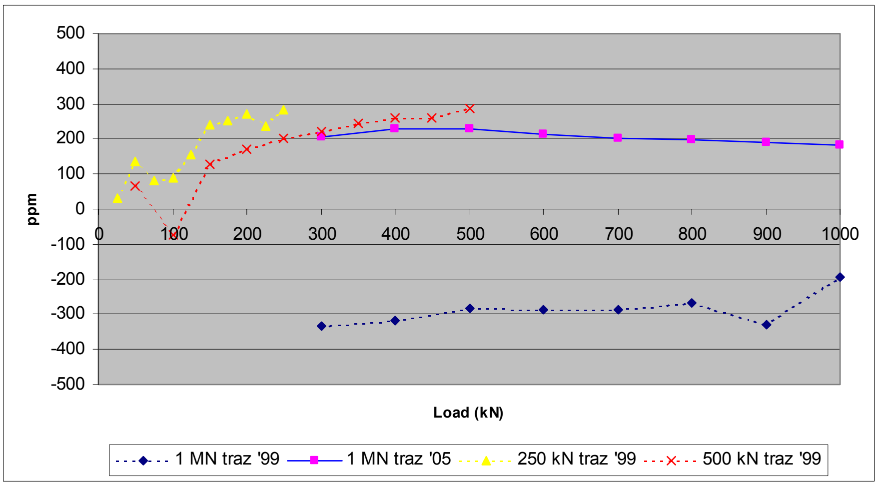

Fig. 5. Long-term data of MTC AEP machines in tension up to 1000 kN.

Fig. 4 shows the relative differences of the results obtained in 1999 and 2005 with dynamometers type AEP-KAL-500 and AEP-KAL-1000 on the 1 MN-INRIM primary standard and on the AEP MTC- 1000 comparison machine in compression.

Fig. 5 shows the relative differences of the results obtained in 1999 and 2005 with dynamometers type AEP-KAL-250, AEP-KAL-500 and AEP-KAL-1000 on the 1 MN-INRIM primary standard and on the AEP MTC-1000 comparison machine in tension.

3. RESULT ANALYSIS

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

3.1 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.

The rotation effect were found to be below 50 ppm for the 50 kN dead weight machine and 100 ppm for the comparison machines, acceptable for these types of force calibration machines and for the load cells used.

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.

3.2 Repeatability

Repeatability 0f the results obtained on the AEP-MCF dead weight machine was of the order of 1 10^{-5} at full scale and certainly within 2 10^{-5} for the part under verification.

3.3 Uncertainty and normalised error En

For the evaluation of the best measurement capability for the AEP accredited Calibration Centre, (< 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 and ISO 376, for all values of force generated, considering both the contributions to uncertainty deriving from relative variation between the AEP calibration machines and INRIM-DWMs, 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

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

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:

Where:
X_{LAB}= the calibration result given by the laboratory
X_0 = the reference value
U_{LAB}= the uncertainty reported by the laboratory
U_0 = the uncertainty of the reference value.
The normalised error En is, as a rule, less than 0,4 for all the calibration machines involved in the intercomparison.

4. CONCLUSIONS

For the evaluation of the best measurement capability, we can say that the uncertainty values estimated during the comparison, are significantly lower than the uncertainty required for calibration of load cells in compliance with the standard UNI-EN ISO 376 and ASTM E74-06, for all values of force generated, considering both the contributions to uncertainty deriving from relative variation between the laboratory and INRiM machines, and those due to repeatability and the rotation effect. In particular:

The metrological procedures applied and the results of the accreditation of the SIT Centre, show that the best measurement capabilities and the total uncertainty, including transfer standards contribution and long term stability, can be considered as well:
± 50 ppm for the 50 kN dead weight machine;
± 250 ppm for the 200 kN Comparison machine;
± 350 ppm for the 1 MN Comparison machine (compression)
± 250 ppm for the 1 MN Comparison machine (tension).

REFERENCES

[1] C. Ferrero," IMGC fra ricerca, disseminazione ed accreditamento", Brescia, 1996.

[2] M.Peters, "Limits to the uncertainty achievable in force transfer", *Weightech* '83, 1983.

[3] C.Ferrero, C. Marinari, "Metrological characterization of load cells by means of different multicomponent calibration systems", *Jurema*, Zagreeb, 1987.

[4] C. Ferrero, C. Marinari, "The dissemination of the Force Unit in Italy", *XVI IMEKO World Congress*, pp. 39-44, Wien, 2000.

[5] GUM: UNI CEI ENV 13005 "Guideline on the uncertainty of measurements"

[6] EA-2/10: “EA Policy for participation in National and International Proficiency Testing Activities”
[7] SIT Doc-511 “Prescriptions on experimental assessments”.
[8] EA-2/03 (EAL P7), “EAL Interlaboratory comparison”, edition 1 March 1996.
[9] C. Ferrero, “The measurement of parasitic components in national force standard machines”, *Measurement*, 8, 1990.
[10] EA 10/04, “Uncertainty of Calibration Results in force Measurements”, 1998.
[11] C. Ferrero, “The EA Mechanical Measurement Activities: Accreditation of Calibration and Testing Laboratories and the Force and Torque Dissemination in Italy”, *International Symposium METROLOGY 2002*, Cuba, 2002, pp.130-160
[12] C. Ferrero, Q. Z. Li, “International comparison of axial load in deadweight force standard machines”, *Proceedings of the 12th IMEKO World Congress*, Beijing, 1991, p. 172-177.