XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

DEVELOPMENT AND METROLOGICAL CHARACTERISATION OF A BUILD-UP FORCE STANDARD UP TO 3 MN

C. Ferrero, C. Marinari, E. Martino

Istituto di Metrologia G. Colonnetti – Consiglio Nazionale delle Ricerche (IMGC-CNR)
Strada delle Cacce 73, 10135, TORINO, ITALY

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 development, construction and preliminary metrological characterization of a Build-Up System (Force Transducers Pyramid Type) are described. In its construction three force transducers, in the nominal range of 1000 kN were used, individually calibrated and later together. Results are given concerning: the evaluation of repeatability, linearity, rotation effect and hysteresis.

Keywords: force-standard, build-up

1. INTRODUCTION

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 the increasing demand from several industrial sectors for calibration and for research on force sensors and load cells for weighing, IMGC has recently acquired two primary force standards of 30kN and 1MN, in addition to those already in the Institute, and has developed a new transfer standard up to 3MN build-up type [2].

In Italy, the force standards are maintained at the National Institute of Metrology G. Colonnetti of the National Research Council (IMGC-CNR). From 10 N to 1 MN, the standards are deadweight machines having $2x10^{-5}$ uncertainty. From 1 MN to 9 MN, a force comparator machine is used, based on reference force transducers of 3 MN to 9 MN capacity with an uncertainty of $5x10^{-4}$, and with traceability to Physikalisch-Technische Bundesanstalt (PTB-Germany).

The present paper gives the main preliminary metrological characteristics (calibration factor, repeatability, rotation effect, hysteresis, etc.) of the new force standard pyramid transducer (build-up type) of 3 MN realised at the IMGC-CNR.

2. GENERAL EVALUATION AND PROCEDURE

The true build-up method consists in placing the dynamometer to be calibrated in series with three reference dynamometers (in parallel to each other). The reference transducers are of equal capacity, at least one third that of the dynamometer to be calibrated, and are located in one plane at three equidistant points around a circumference.

The four dynamometers are then loaded using a hydraulic press, so that the load axis passes through the axis of the dynamometer to be calibrated and through the centre of the circumference, defined by the three reference dynamometers.

For the three reference dynamometers, the calibration curve, obtained for example with a standard machine having higher metrological characteristics, is known.

The load on the dynamometer to be calibrated is thus provided as the sum of the loads applied to the single reference dynamometers.

Application of the "build-up" method also requires:

- The correct geometric disposition of the load cells used as reference for the calibration;
- Spurious components of load to be minimized, i.e. transversal components and bending moments;
- The load must therefore act on the same axis and centred with the four cells so as to minimize these components;

The three force transducers employed in the Build-Up prototype were chosen starting from a set of six force measuring transducers, in the nominal range of 1000 kN.

The assembled Build-up prototype was then calibrated on the IMGC-CNR Force Standard Dead Weight Machine (DWM) and the overall results were compared with the previous one.

3. THE BUILD-UP SYSTEM

3.1. Force Transducers

The three force transducers employed in the Build-Up prototype were chosen starting from a set of six load cells (type AEP- KAL –1000 kN) with nominal range of 1000 kN, shown in figure 1

The internal structure of the force transducers consists of an spoke element type These transducers are able to resist up to 150% of overload and are extremely resistant to transversal load.

Fig. 1**.** The three force transducers analysed and calibrated for the Build-up prototype

3.2. Mechanical Arrangement

The load cells are arranged in such a way that the forces applied to the build-up force transducer are well defined in order to reduce the parasitic components.

The mechanical arrangement (Fig. 2 and 3) could be described as in the following:

1) A base plate where are placed the three force transducers. The load cells are mounted at the apexes of an equilateral triangle. The plate has a system to centring the build-up on the dead-weight machine;
2) A mounting pad for each force transducer. These pads are rectified (parallelism better than 0,02 mm/m
3) The loading pads to transmit the forces to the sensors head. They are made of hardened steel 58-60 HRC and centred on the transducer head by a spherical cup.
4) The alignment plate centres the loading pads and the in-line ball and socket joint on the sensors.
5) Three axial ball and socket joints to transmit the forces to the normal to the sensor heads to avoid parasitic moments.
6) A force distribution plate to distribute the force equally onto the three reference force transducers. This plate is extremely thick (450 mm) to limit the deformation and associated parasitic components.
7) The mounting pad holds the sensor to be calibrated.

The assembly is built to high precision to provide close alignment:

- the eccentricity of the upper mounting pad with respect to the base plate is less than 0,2 mm;
- the two external plates are parallel to better than 0,03 mm/m;
- the mounting pads are adjusted so that the three columns (force transducer and pads) are the same height better than 0,01 mm.

Fig. 2**.** Build-up prototype before to be assembled

Fig. 3: Base plate and loading plate

4. CALIBRATION

To acquire the measurement data, the three force transducers were connected in turn to a HBM-DMP 40, with a VT 16 distribution board using channels.

During the individual force transducers calibration (Fig. 4), in order to avoid differences from the impedance effects of the Build-Up prototype, we had the special care to maintain them connected to the distribution board VT-16, in the same manner the transducers are used in parallel in the final pyramidal system [1,3,6].

The various test cycles were performed by increasing the load until the rated load was reached, with increments as far as possible of equal size.

Fig. 4: Single load cell calibration on the IMGC-CNR 1 MN deadweight machine

4.1. Individual Calibrations up to 900 kN and 300 kN
The following characteristics of each force transducer were analysed by using the IMGC 1MN Dead-Weight Machine (DWM): calibration factor, repeatability with and without rotation, hysteresis, zero variations at zero load.
The calibrations were performed up to 300 kN and 900 kN, in order to compare the individual results with the results obtained with the three force transducers connected all together. Calibrations were repeated three times over six months, to check the individual drift, before assembly the pyramidal structure.

The repeatability with and without rotation was determined on the six force transducers, in the conditions provided for in the standard [EN 10002/3, ISO 376]:

a) two or three cycles during which the cell is always in the same angular position (repeatability without rotation)
b) three or four cycles during which the cell is rotated around its own axis (repeatability with rotation).

After the metrological characterisations of the six load cells, the three force transducers with the high metrological characteristics, such as: good repeatability, low creep, low rotation effect, and above all, good stability over time. were chosen

Tables 1, 2 report the repeatability values with and without rotation for the three reference force transducers (A, B, C), for different axial loads up to 300 kN and 900 kN.

Repeatability: the results show that it is better in case (a) (without rotation) than in case (b) (with rotation). The rotation effect thus worsens repeatability, as occurs for most force transducers. For all the three load cells the dispersion of the calibration factor decreases as the load increases; for small loads, as has been shown in detail with multi-component measurements, the interface effects and the machine-dynamometer interaction are more significant.

The temperature sensitivity as given by the factory is of the order of St = 0,001% /K

4.2. Calibration of the Build-up System

The Build-up prototype was calibrated on the IMGC DWM

After performing the individual calibrations and validation tests, it was proceeded to the calibration of the Build-Up prototype, that is, the three force transducers of 1000 kN coupled in parallel,
The prototype was set up and calibrated simultaneously up to the capacity of 900 kN.
Forces are generated by DWM up to the capacity of 1000 kN, with the expanded relative uncertainty of 2 x 10^{-5}.

Fig. 5. IMGC-CNR - Force standard machine of 1 MN with the 3 MN Build-Up Force Transfer Standard

5. RESULTS ANALYSIS

Tthe most relevant values obtained during the calibrations, such us repeatability with and without rotation errors, and the determination of the relative expanded uncertainty is reported in the following tables.

The zero load values referred to the maximum load are in the same order for the three load cells; the maximum value did not exceed 2x10^{-5}. These values appear to be fairly independent of time, after an initial period of ageing. The hysteresis were within the normal values for load cells with elastic elements of this type (from 150 to 300x 10^{-6}).

The evaluation of the expanded relative uncertainty of measurements of the build-up system has been made by using a traditional laboratory procedure [6].

TABLE 1. Repeatability with and without rotation up to 900 kN

	Without rotation			With rotation		
Force [kN]	A $[10^{-5}]$	B $[10^{-5}]$	C $[10^{-5}]$	A $[10^{-5}]$	B $[10^{-5}]$	C $[10^{-5}]$
150	3	3	3	10	12	12
300	0.7	1	1	6	6	7
450	.0.15	0.2	0.2	6	6	6
600	0.1	0.2	0.2	4	4	5
750	0.3	0.1	0.1	3	3	3
900	0.5	0.2	0.2	2.5	3	2.5

TABLE 2. Repeatability with and without rotation up to 300 kN

	Without rotation			With rotation		
Force [kN]	A $[10^{-5}]$	B $[10^{-5}]$	C $[10^{-5}]$	A $[10^{-5}]$	B $[10^{-5}]$	C $[10^{-5}]$
50	3	2	4	1	6	7
100	0.1	0.1	1	8	1	8
150	.0.8	0.1	0.8	8	7	7
200	0.5	0.25	0.25	7	6	8
250	0.8	0.2	0.2	6	6	8
300	0.8	0.1	0.15	5	5	7

6. CONCLUSIONS

The results of the individual calibrations performed at IMGC are in good agreement with the preliminary results obtained on the complete Build-Up Reference System (the relative deviation is of the order of $2x10^{-4}$

Otherwise the use of force comparator machines as standard machines requires great care, because the main errors could be originated by the reference build-up transducers and by the characteristics of the systems to generate and transfer the loads

A merely theoretical evaluation of the comparator machine may be not sufficient. For this reasons inter-comparisons are in program between Primary Institutes of Metrology, within the EUROMET Project (IMGC, PTB-Germany) and in the framework of bilateral agreements (NIM-People's Republic of China and NIST-USA).

TABLE 3. Expanded Uncertainty Evaluation

	Probability distribution	Standard uncertainty
Individual calibration of the 1 MN force standard transducers		
• Reference force applied	• Normal	$2\ 10^{-5}$ (K=2)
• Resolution	• Rectangular	
• Repeatability without rotation	• Rectangular	
	• Rectangular	
• Repeatability with rotation	• U shaped	
• Reversibility	• Rectangular	
• Zero error	• Rectangular	
• Interpolation error	• Rectangular	
• Total calibration uncertainty	• Triangular	$8\ 10^{-5}$ F/3
Using of the Force Transducers		
• Creep (30 min.)	• Normal	$0{,}3\ 10^{-4}$ F/3
• Long time drift	• Rectangular	$0{,}8\ 10^{-5}$ F/3
• Temperature drift (2° C)	• arcsine	$0{,}15\ 10^{-4}$ F/3
$u_c^2 = (8\ 10^{-5}\ F/3\ )^2+(0{,}3\ 10^{-4}\ F/3)^2+(0{,}8\ 10^{-5}\ F/3\ )^2+(0{,}15\ 10^{-4}\ F/3)^2 = (\ 8{,}4\ 10^{-5}\ \ F/3)^2$		
BUIL-UP $3\ u_c^2 = 3(8{,}4\ 10^{-5}\ \ F/3\ )^2 = \ 2{,}3\ 10^{-9}\ F^2$		
Force generating system		
• internal coherence of the masses		
• intercomparison		$0{,}8\ 10^{-4}$ F
Build-up system	$u_c^2 = 2{,}3\ 10^{-9}\ F^2 + 6{,}4\ 10^{-9}\ F^2 = 8{,}7\ 10^{-9}\ F^2$ $u_c = 0{,}93\ 10^{-4}$ F $U = 2\ u_c = 1{,}87\ 10^{-4}$ F $b_{mc} = 2\ 10^{-4}$ F	

REFERENCES

[1] A. Gizmajer, "Some improvements in the Build-up System", *Round Table, IMEKO XII*, Beijing, 1991

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

[3] H. Wieringa., "Design of 1,65 and 4,95 MN Transfer Standard Based on the Build-Up Procedure", *Proc. 10th Conference of IMEKO TC-3 on Measurement of Force and Mass*, Kobe, Japan, September 1984, pp. 205-208.

[4] EN 10002-3:1994 – "Metallic Materials - Tensile Testing - Calibration of Force Proving Instruments Used for the Verification of Uniaxial Testing Machines".

[5] EA 10/04 – "Uncertainty of Calibration Results in force Measurements", *European co-operation for Accreditation.*

[6] A. Gosset, "Workshop on statement of uncertainty force standard machines", *EUROMET Project 310*, 1994

Authors: Carlo Ferrero, Istituto di Metrologia "G. Colonnetti", Strada delle Cacce, 73; Torino -10135 Italy. Phone int.: +39 011 3977352; Fax int.: +39 011 3977 503. E-mail: C.Ferrero@imgc.cnr.it

Carlo Marinari, Istituto di Metrologia "G. Colonnetti", Strada delle Cacce, 73; Torino -10135 Italy. Phone int.: +39 011 3977377; Fax int.: +39 011 3977 426. E-mail: C.Marinari@imgc.cnr.it

Emanuele Martino, Istituto di Metrologia "G. Colonnetti", Strada delle Cacce, 73; Torino -10135 Italy. Phone int.: +39 011 3977352; Fax int.: +39 011 3977 503.