Proceedings of the 17th International Conference on Force, Mass, Torque and Pressure Measurements,
IMEKO TC3, 17-21 Sept. 2001, Istanbul, Turkey

Long-Term Stability of the IMGC Reference Force Transducers up to 9 MN

C. Ferrero, C. Marinari
Istituto di Metrologia "G. Colonnetti" (IMGC-CNR)
Turin, Italy

Abstract

Force transducers are calibrated using dead-weight, lever multiplication or hydraulic multiplication standard machines. For very large capacities, in general above 1 MN, the "build-up" method may be employed, consisting of comparing the dynamometer to be calibrated with one or more dynamometers linked in parallel. With the "build-up" method the field of force measurement may be extended to values that would not appear possible with the use of dead-weight or multiplication primary standards, at a much lower cost. The present paper reports the evolution over time, that is the long term stability of the metrological characteristics (calibration factors, repeatability, hysteresis and zero variations at no load) of two reference transducers (3 MN and 9 MN respectively) used to calibrate force transducers at IMGC-CNR.

1. Introduction

The measurement of a physical quantity needs 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.

The weight-force is transferred to secondary standards by means of force standard machines having large dimensions and high accuracy/1,2,3/.

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 100 kN to 1 MN, a hydraulic-amplification machine, of uncertainty lower than $2x10^{-4}$, can be used./4/

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 5×10^{-4}.

The calibration forces are generated by a four columns hydraulic system and measured by reference force standards with traceability to Physikalisch-Technische Bundesanstalt (PTB-Germany).

The present paper describes the long term stability of the main metrological characteristics (calibration factor, repeatability, rotation effect, hysteresis, etc.) of the two reference standards of 3 MN and 9 MN, evaluated on the calibrations carried out in PTB in a period of 15 years, under a PTB-IMGC bilateral agreement and the Euromet project on traceability.

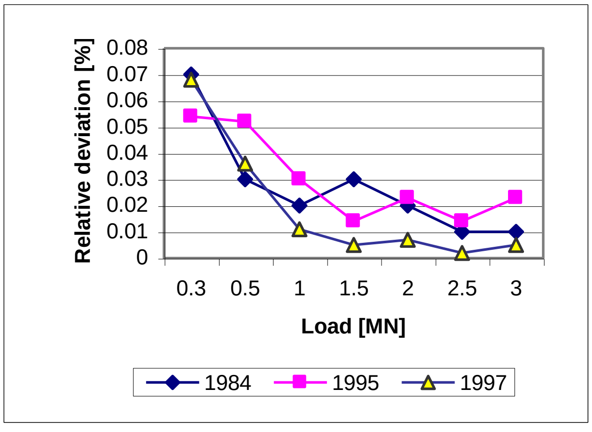

Figure 1. N. 174 3 MN load cell - Rotation effect

The calibration curves of the two reference cells measured in 1984, 1988, 1991 1995, 1997, and 1999 at PTB are also compared with the calibrations performed on IMGC 1MN HM standard machine.

2.General Evaluation of the Build up Method

The term " build-up method" strictly speaking refers to two different configurations:

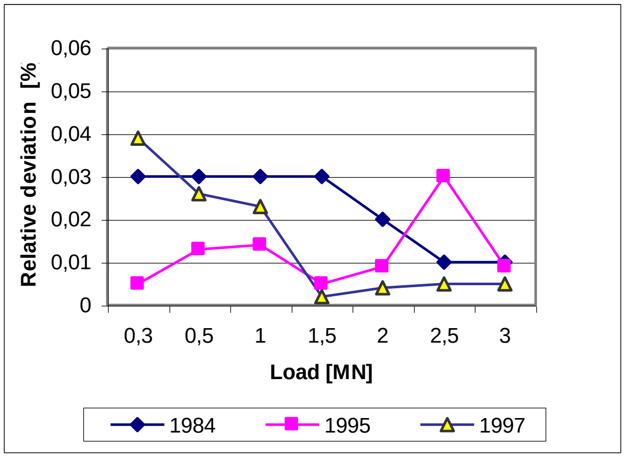

Figure 2. N. 174 3 MN load cell - Repeatability

a) 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 [5], [6], [7].

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.

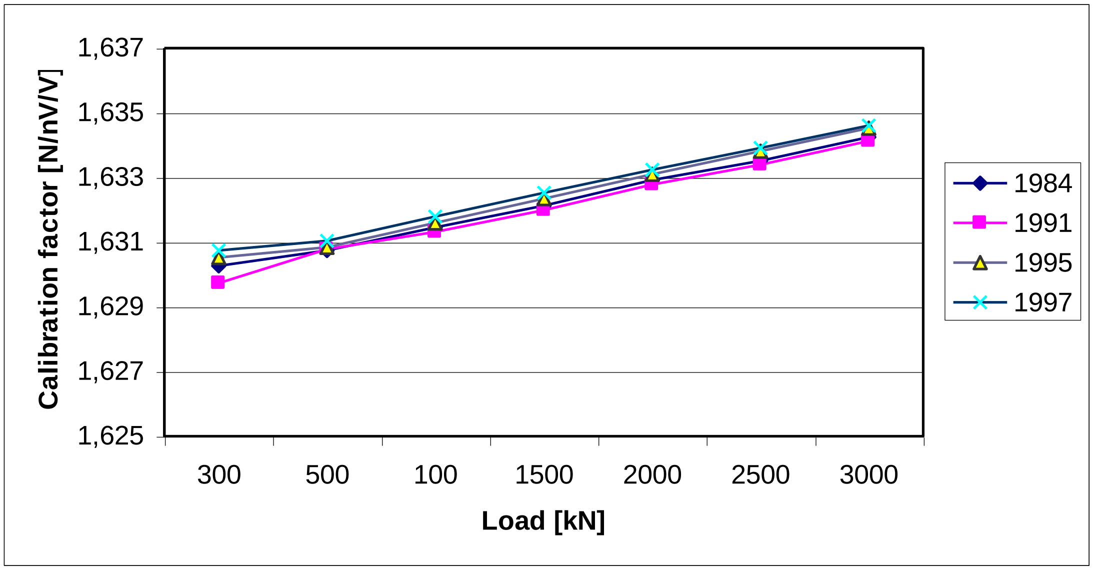

Figure 3. N 174 3MN load cell - Calibration factor

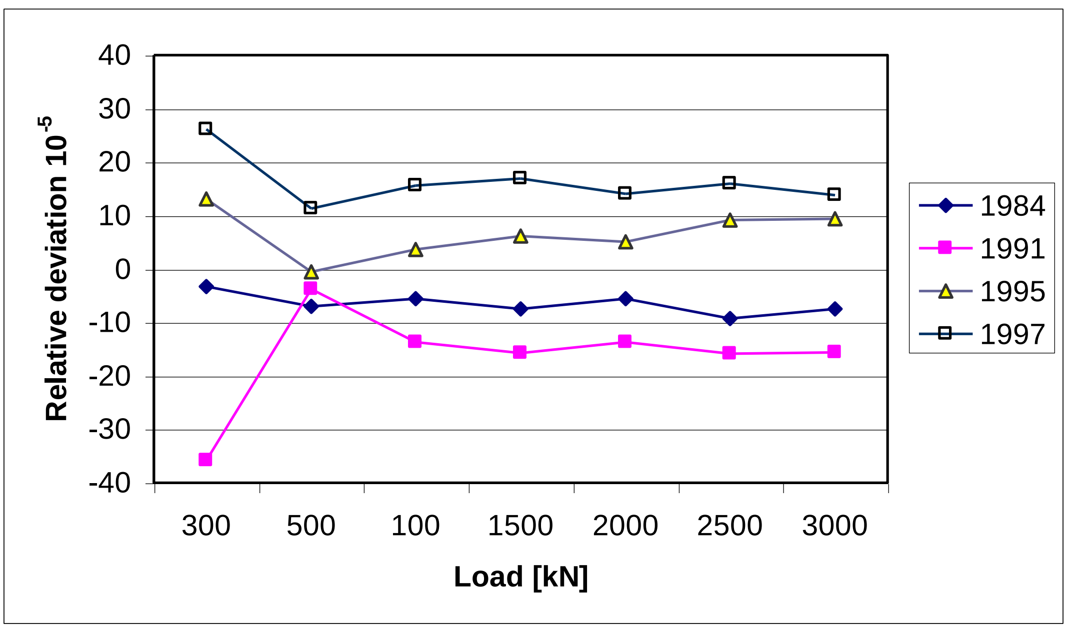

Figure 4. N. 174 3 MN load cell

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 mechanical structures coupling and transmitting the load used must possess appropriate characteristics: each dynamometer must for instance be positioned on a rectified plate of high hardness and the load must be applied through a plate resting on the head of the dynamometers shaped like a spherical cap.

b) The reference force transducer method, which consists in placing the dynamometer to be calibrated in series with a reference dynamometer of equivalent capacity to it.

The two dynamometers are then loaded by a hydraulic press, so that the load axis passes through the axis of the two dynamometers. For the reference force transducer, the calibration curve, obtained for example with a standard machine, is known.

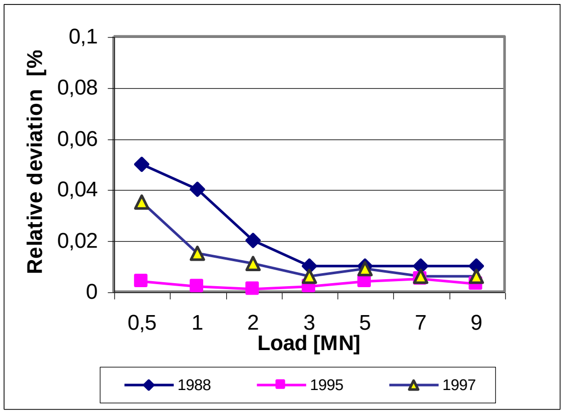

Figure 5. N 179 9 MN load cell - Repeatability

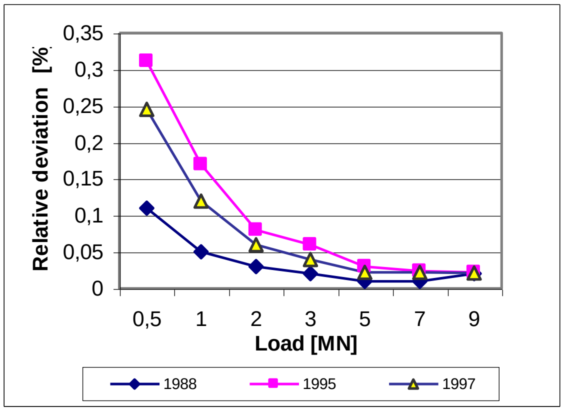

Figure 6. N. 179 9 MN load cell - Rotation effect

The paper refers to method (b), although the considerations may immediately be extended to case (a).

The main limitations of both methods are linked to:

The load generation system: the movement of the pistons of the hydraulic press during application of the load must be as close as possible to pure translation;

The availability of reference transducers with high metrological characteristics, such as: high accuracy, low creep, low rotation effect, and above all, good stability over time.

3. Experimental Results and Analysis

The elastic element of the load cells used at IMGC comprises a solid cylinder with a flat lower surface and an upper surface in the form of a spherical cap.

The 3MN cell has diameter 110mm and height 330mm, while the 9MN cell has diameter 200mm and height 400mm.

The results of the calibration made using the Physikalisch-Technische Bundesanstadt dead-weight hydraulic amplification machine (capacity 16,5MN, declared uncertainty $2x10^{-4}$) are compared. The calibrations were done in 1984, 1988, 1991, 1995 , 1997 and 1999 for the 9MN cell and in 1984, 1991 1997 and 1999 for the 3MN cell.

The following characteristics of each reference transducer were compared: calibration factor, repeatability with and without rotation, hysteresis, zero variations at zero load.

The repeatability with and without rotation was determined in the conditions provided for in the standard [EN,DIN], in two conditions:

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)

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.

It should be remembered that, given the long time interval considered, the standards applied by PTB to calibrate the dynamometers changed (DIN 51301 until 1988, which provided for three cycles at 0° with four angular positions: 0°, 90°, 180° and 270°; and EN 10002/3 after that, which entailed two cycles at 0° with three angular positions: 0°, 120° and 240°).

To determine the hysteresis, and in particular its value at 50% of the rated load, test cycles with increasing and decreasing loads were performed. For each test cycle, the zero load signal was determined.The most important results are reported in the following Figures and Tables.

Figures 1, 2, 5 and 6 report the repeatability values with and without rotation for the two reference transducers, for different axial loads for the period 1984 to 1997

Figures 3 and 7 show the calibration factors of the two load cells during the 13 years since the first evaluation, while Figures 4 and 8 show the variation of the calibration factor from the average value.

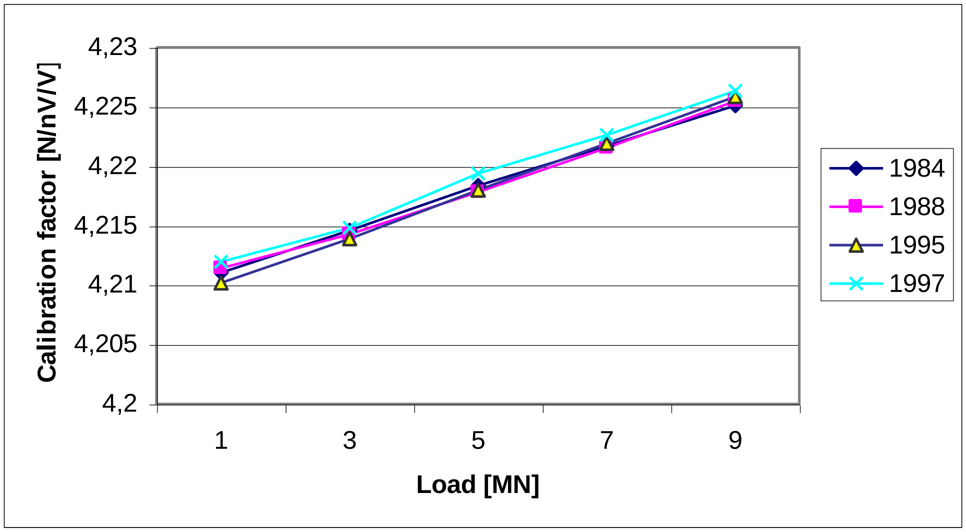

Figure 7. N. 179 9MN load cell - Calibration factor

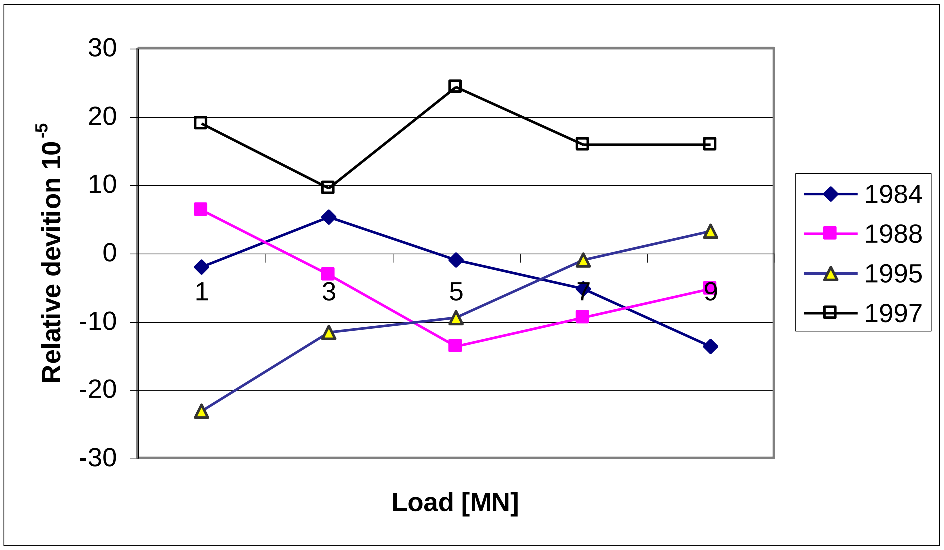

Figure 8. N. 179 9 MN load cell

For comparison purposes, Fig. 9 reports the calibration factors for the 3MN dynamometer, for the 4 cycles done in the different angular positions, in accordance with standard EN-10002/3, at PTB, and the average values obtained on the 1MN-IMGC HM up to 30% of full scale of the reference standard. The relative differences are of the order of the declared uncertainty ($2x10^{-4}$).

The most important evaluations are as

follows:

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 both 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 calibration factor [in N/mV/V] of both cells decreases as the load increases, these being compression load cells with a solid cylinder elastic element.

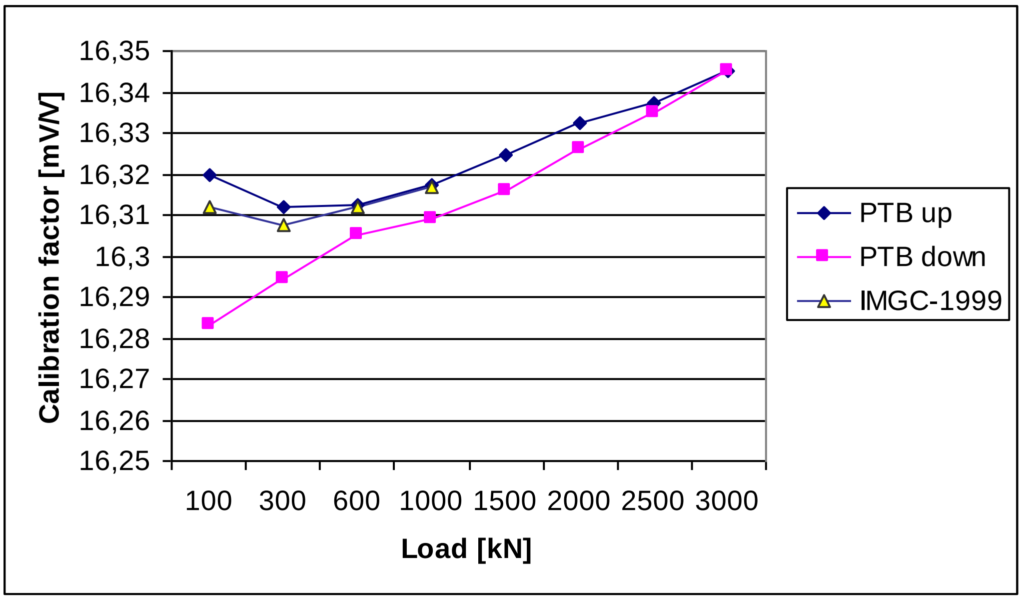

Figure 9. Comparison between calibration factor of 3MN load cell, for tests carried out on PTB 16,5 MN hydraulic standard machine and IMGC 1MN hydraulic standard machines

The variations in the calibration factor were within $3x10^{-4}$ from 1984 to 1997 for the two 3MN and 9MN reference standards, and within 1,25 10^{-4} from '95 to '97 for the 9MN , and within 0,5 10^{-5} for the 3MN load cells. The zero load values referred to the maximum load are in the same order for both load cells; the maximum value did not exceed $3x10^{-4}$. 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 300 to 600x 10^{-6}). For both cells the hysteresis values increased slightly over time.

4. Conclusions

The results of the calibrations performed at PTB over the last 17 years not only confirm the principal considerations expressed after the first decade of use of the IMGC-CNR reference standard, they also enable us to make the following evaluations:

The two reference force standards showed an average stability of the order of $2x10^{-4}$ over four years. Otherwise the use of force comparator machines as standard machines requires great care, because the main errors could be originated by the reference transducers and by the characteristics of the systems to generate and transfer the loads. It is thus advisable to check the calibration characteristics of the load cells with a frequency depending on the conditions of their use, and on the number of calibrations performed.

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).

5. References

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

[2]. Weiler W., Sawla A., *Force standard machines of the National Institute for Metrology*. PTB - Bericht ME-22, 1978

[3]. Weiler W., Sawla A., *Force standard machines of the National Institute for Metrology*. PTB – Bericht ME-62, 1984

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

[5]. Brandenburg P.J., Wieringa H., *Design of high-precision force transducers with capability of 1,65 and 4,95 MN and their use as transfer standards,* PTB - Bericht ME-17, 1990

[6]. Gizmajer, A., *Some improvements in the Build-up System*, RT, IMEKO XII, Beijing, 1991

[7]. Gizmajer, A., *Experience with the build-up system at PKNMiJ Report from the CCM meeting*" PTB, Germany, 1990

Contact Person for Paper :

Dr. Carlo Ferrero
IMGC-CNR , 73 Strada delle Cacce, 10135
Torino - Italy
Fax: +390113977503
Tel: +390113977352
e-mail: c.ferrero@imgc.to.cnr.it