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Research, Development and Characterization of a Build-up System Prototype up to 600 kN

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Abstract

This paper describes the research, development, construction, validation tests and metrological characterization of a Force Transducers Pyramid prototype (Build-Up System), in the nominal range of 600 kN. This system is used for the standardization and dissemination of the physical magnitude force, propitiating the utilization of alternative system for calibration of force measurement instruments, such as: force transducers, load cells, proving rings and scales of testing machines. In its construction three force transducers, in the nominal range of 200 kN were used, individually calibrated and later together. In its characterization, a force standardization machine in the nominal range of 1000 kN and a hydraulic force generating machine of 1000 kN were used, both installed in the Force and Hardness Laboratory (LAFOR), of the National Institute of Metrology, Standardization and Industrial Quality (INMETRO). By this way it is intended to transfer and to implant this technology widely spread abroad, to the Brazilian metrological force measurement field.

1. Introduction

Since the sixties [1,2], in the metrological standardization institutes and in the industrial field, testing machines and machines of force generation that exceed the available measurement range of force transducers, has been needing to be measured and calibrated. In the more developed countries these forces are measured usually by the force transducers method named Build-up Method or Force Transducers Pyramid, in which groups of three or multiple of three transducers are disposed in parallel [3]. This method is quite efficient and it substitutes with great advantages and economy of resources the Force Standardization Machines of high capacity. These types of machines are constituted of deadweights of great dimensions or machines by mechanical/hydraulic amplification, both with high level of economical investment.

2. Build-up Prototype Design

The structural prototype design was developed to support the application of forces up to 1000 kN in compression. Taking in account the available force transducers, the metrological validation tests were only implemented up to 600 kN, however we intend to expand the range of measurement to the design nominal load.

In agreement with the available literature and following Prof. G. Barbato's orientation, the fundamental principle is to understand that the force on a Build-Up is measured as being the sum of the forces that go by the three force transducers coupled in parallel in the base of the Build-Up. Its structure needs to be designed so that the nominal force is subdivided by the three force transducers, acting on them in the same way for which happened during the phase of individual calibration of each one of the transducers and with the smallest possible deformation on the distribution and support plates of the Build-Up.

3. Structural Calculation

After the model analysis of the Build-Up prototype and comparing it with the classic solutions from the traditional literature on circular plates, we had find a close example of a circular plate with three support points distributed to 120º in the diameter of the plate. The model that was more approached to the real condition of work, in which a circular plate with their ends simply supported with a concentric force was according to reference [4].

Taking into account the work characteristics in which the structure is submitted and basing on the specific papers on build-ups, there was not concern with the active tensions in the structure, but more attention with the displacements, because this type of arrangement should present the minimum mechanical deformation.

In order to verify the theoretical above described structure, we used a fine elements method (FEM) to analyze the model that was more close to the real situation, using a structural analysis software, SAP 90 - Structural Analysis Program, version 5.43, developed by the California University, Bekerley.

This model was divided in two parts, the first one only the distribution plate and the second one, the distribution plate with the superior kneecap.

To facilitate the understanding of these models we show the general arrangement of the force transducers pyramid, at the figure 1 below.

The contact surface between the distribution plate and the kneecap top base, for the second model was made by the compression springs simulation, so that the software assumed an homogeneous distribution for the force, how the good practice of engineering recommends.

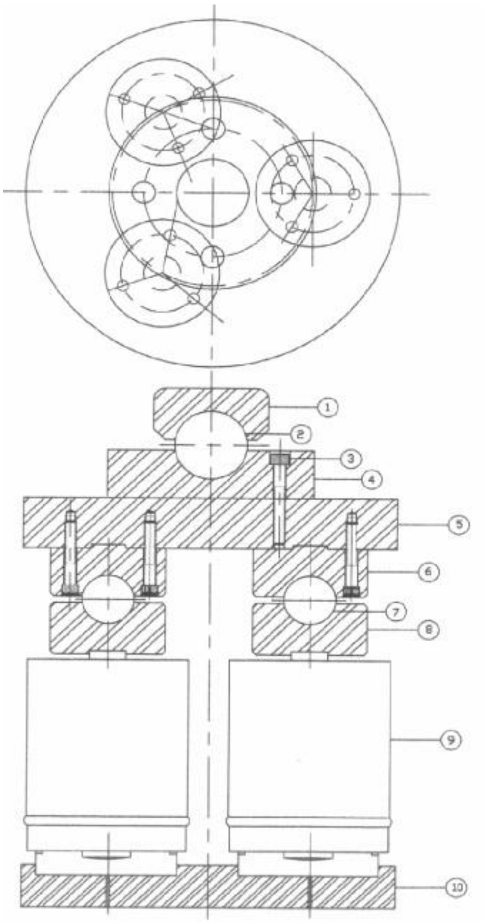

Figure 1. 600 kN Build-up Prototype

Description

① superior kneecap	⑥ middle plate
② steel sphere Ø 63,5 mm	⑦ steel sphere Ø 45,0 mm
③ M10 DIN 912 screw	⑧ kneecap bottom base
④ kneecap top base	⑨ force transducer
⑤ distribution plate	⑩ base plate

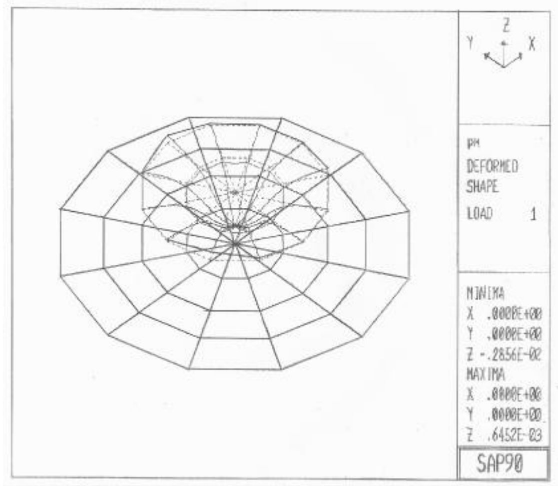

Figure 2. Deformed distribution plate with the top kneecap

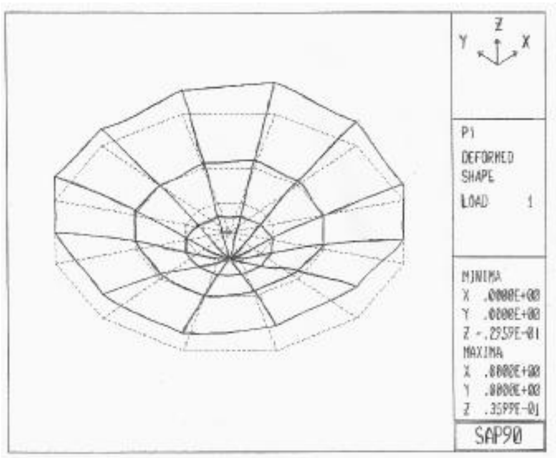

Figure 3. Deformed distribution plate without the top kneecap

As already described previously, the obtained results through the simulations above described can be verified in the figures 2 and 3.

4. Force Transducers

The force transducers employed in the Build-Up prototype were chosen starting from a set of four force measuring instruments, model PR 6222/24, in the nominal range of 200 kN, available at the laboratory, see figure 4 below.

They are instruments tightly protected by a carcass in painted stainless steel being appropriate for job in extremely adverse environmental conditions.

Figure 4. The four force transducers analyzed and calibrated for the Build-up prototype

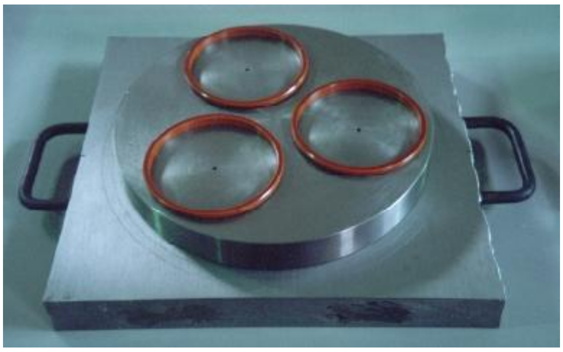

Figure 5. Base plate of the Build-up prototype

The internal structure of the force transducers consists of an elastic element type column mounted with a Wheatstone bridge. The element spring type column is projected to measure axial loads and typically it possesses the minimum of four strain gauges, being two in the longitudinal direction and two guided obliquely to measure the tension of Poisson. The strain gauges are connected to form a complete bridge circuit.

These transducers are capable to resist up to 200% of overload without damage or loss of function and extremely resistant to vibrations in function of its robust construction.

4.1. Mechanical Arrangement

Taking into account the perfect alignment and joining of the three force transducers selected, starting from the individual calibration, it was designed and built a circular base with three equidistant grooves (fig. 5) forming the vertices of an equilateral triangle, in order to get the most exact subdivision of the applied force in the center of the prototype. [1]

To acquire the measurement data, the three force transducers are joined in a DK 38 S6 D20 unit, with a VT 16 distribution board using channels: 0, 1, 2 and 3.

5. Individual Calibrations up to 200 kN

The metrological tests to characterize the prototype behavior were consisted of several calibrations, following the established methodology in national and international standards with the objective to know the transducers exactly, their adjustment curves, the errors, associated uncertainties and their classification according to each one of those standards.

First of all we started with the individual calibrations of the four force transducers (fig. 4) by the Brazilian standard NBR 6674:1999, similar to the EN 10002-3:1994 (European) and by the ASTM E 74/95 (American) used for these calibrations.

In the figure 6, below a view of the Force Standard Machine employed can be observed, appearing at the first plan the machine part where forces are generated by mechanical amplification up to the capacity of 1100 kN, with the expanded relative uncertainty of 1 x 10^{-4}.

Figure 6. INMETRO/Brazil - Force standard machine of 1 MN

During the force transducers calibration, 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, and when coupled in parallel in the pyramid according to Carbonell [5].

After the realization of the metrological tests, it were chosen the three force transducers that best carries out had, in accordance with the two applied methodologies calibration standards

6. Calibration of the Build-up System

The Build-up prototype was calibrated at the INMETRO's Force Reference Machine.

After performing the individual calibrations and validation tests, in comparison with a set of 04 (four) force reference transfers of 100 kN, 200 kN, 500 kN and 1000 kN, using a Hydraulic Force Generation Machine of INMETRO, it was proceeded to the calibration of the Build-Up prototype, that is, the three force transducers of 200 kN coupled in parallel, and in series with a transfer of 1000 kN, according figure 6.

The prototype was set up and calibrated simultaneously up to the nominal capacity of 600 kN, following the criteria proposed in the standards, Brazilian [6], European [7} and American [8], that establish different tests, data treatment and different classification.

The objective of the realization of the calibrations follows the same procedure that are proposed in recent experiments of pyramids, developed in Germany [9], Spain [5] and Romania [10].

7. Data Treatment

Below we present tables and graphs demonstrating the most relevant values obtained during the calibrations, such us repeatability and reproducibility errors, normalized error, and the determination of the relative expanded uncertainty.

Table 1. Expanded Uncertainty Evaluation

Measuring Range	Expanded Uncertainty U_{ref}	Expanded Uncertainty U_{pyr}
kN	kN	kN
60	3,9E-02	2,8E-02
120	3,9E-02	4,3E-02
180	4,4E-02	5,5E-02
240	5,2E-02	5,3E-02
300	5,4E-02	5,2E-02
360	5,4E-02	4,8E-02
420	6,0E-02	5,0E-02
480	6,3E-02	5,2E-02
540	6,6E-02	5,5E-02
600	6,9E-02	6,1E-02

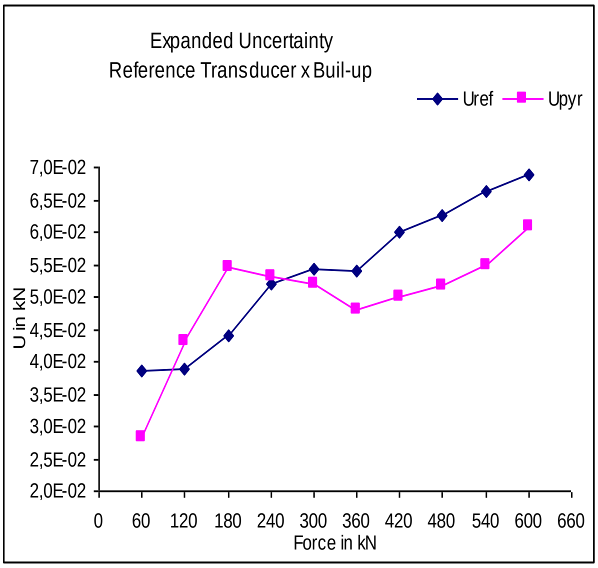

Figure 7. Expanded Uncertainty up to 600 kN

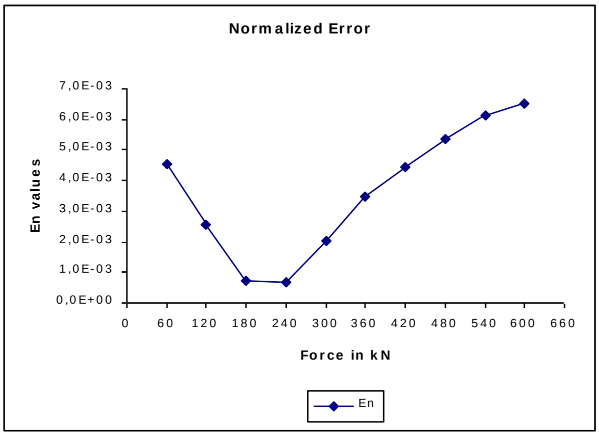

Figure 8. Normalized error up to 600 kN

Table 2. Normalized error

Measuring Range	Normalized Error
kN	
60	4,5E-03
120	2,6E-03
180	7,2E-04
240	6,6E-04
300	2,0E-03
360	3,5E-03
420	4,5E-03
480	5,4E-03
540	6,1E-03
600	6,5E-03

Table 3. Expanded uncertainty of hydraulic machine

Measuring Range	Hydraulic Machine Expanded Uncertainty Umach
kN	kN
60	9,9E-02
120	1,9E-01
180	4,1E-01
240	3,7E-01
300	4,6E-01
360	5,5E-01
420	6,4E-01
480	7,2E-01
540	8,3E-01
600	9,1E-01

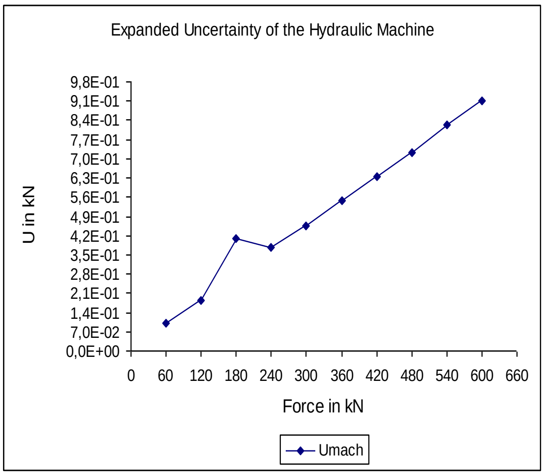

Figure 9. Expanded uncertainty of hydraulic machine

8. Discussion

After the realization of several metrological tests to characterize the prototype behavior we can affirm that the results were considered satisfactory under the evaluation methodologies to calibrate force transducers.

The specific parameters are established in the standards and specific documents to determine errors and uncertainty associated to force measuring instruments [6], [7], [8] and [11].

Taking into account the results analysis starting from the NBR 6674:1999 methodology calibration, we verified that the pyramid force transducers, when analyzed individually, they under the classes G 0,5; G 1 or G 2, however when coupled and tested together, they obtained class G 00, the most select class from the referred standard.

9. Conclusions

Taking the available resources at the Force and Hardness Laboratory of INMETRO, an experimental system was developed and it was realized all metrological tests and comparisons.

The figure 10 bellow, shows the complete system, where its possible to see the digital measurement unit device, DK 38 S6 D20, that was used for the data acquirement, the Distribution Plate, VT-16, where the four force transducers were connected simultaneously and the Build-up Prototype totally mounted, with the specific configuration for testing machines scales calibration.

By the first time in Brazil a Build-up Prototype as a Force Standardization System was developed. The obtained results are significant by the point of view of the technology transference.

Figure 10. Build-up prototype

It assures the possibility to invest in this kind of force standardization system, for high capacities, because it was demonstrated that now we have the necessary conditions to continue in this way.

They allow the reproduction of the greatness forces and the results are totally tracked to the national patterns.

It was also demonstrated that is possible to develop a system up to 3 MN, starting from the calibration of three force transducers of 1 MN, by the INMETRO's Force Standardization Machine.

The disturbance forces effect, such as transverse forces and moments might have contributed to some discrepancies.

The employed hydraulic machines generators during the validation tests measurements, are not appropriate as force generator systems for this kind of prototype in study. The two unloading readings series, as established at the validation procedure, as well as in at the American Standard were realized without the possibility of stabilizing the several steps of force.

A force transducer incorrect positioning at the Build-Up base plate, can be a source of systematic errors for the behavior evaluation in this type of standardization system.

The Build-up System is an efficient method for force measurement calibration and testing materials scales, over 1 MN.

10. Recommendations

It is fundamental that in the evolution of this Standardization System the data acquirement will be implemented in real time, through the use of new one digital measurement units available at the market.

To develop Build-up Systems with capacity over 1 MN it is recommended the research of force transducers, especially designed for measurements.

To develop a project of a Force Generator, in the nominal range of 10 MN, with mechanical characteristics of high stability and accuracy at the several steps of force, that it will be applied.

To realize new metrological tests seeking to enlarge the nominal range of the prototype, up to 1 MN, once the transducers of 200 kN admit use 200% above its nominal capacity, without damage of their technical characteristics.

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11. References

[1]. Bray A., Barbato G. and Levy R., *Theory and Practice of Force Measurement*, Academic Press Inc., San Diego CA 92101, Academic Press Limited 24/28 Oval Road London NW1 7 DX, pp. 129 – 134.

[2]. Bray A., Franceschini F. and Barbato G., *The stability of two large capacity load cells used as reference force standards*, OIML Bulletin, Volume XXXVI, Number 3, July 1995, pp. 22 – 25.

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

[4]. Ugural A. C., *Stresses in Plates and Shells*, Mc Graw-Hill, New York, 1984.

[5]. Carbonell J. A. R., García J. A. F., Verdecia J. R. and Robledo A. L., *Characterization of the 2 MN Hydraulic Force Comparator Machine of CEM*, Proceedings of the IMEKO TC-3/APMF'98, 16th International Conference on Force, Mass and Torque Measurements in Parallel with Asia-Pacific Symposium on Measurement of Mass and Force, September 14 – 18, 1998, Taejon, Republic of Korea, pp. 383-388.

[6]. NBR 6674:1999 – *Materiais Metálicos – Calibração de Instrumentos de Medição de Força Utilizados na Calibração de Máquinas de Ensaios Uniaxiais*.

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

[8]. ASTM E 74/95 - *Standard Practice of Calibration of Force Measuring Instruments for Verifying the Force Indication of Testing Machines*.

[9]. Anderegg P., Honegger W., Sennhauser W. ,Kumme R. and Sawla A., *Development and Calibration of a Build-Up System for Forces of up to 21 MN*, Proceedings of the IMEKO TC3/APMF'98, 16th International Conference on Force, Mass and Torque Measurements in Parallel with Asia-Pacific Symposium on Measurement of Mass and Force, September 14 – 18, 1998, Taejon, Republic of Korea, pp. 45 – 53.

[10].Marinescu A. and Peschel D., *Specification and Uncertainty of the 32 MN Force Calibration Machine of ICMET/Romania*, Proceedings of the 14th IMEKO TC-3 Measurement of Force and Mass International Conference, Warszawa, Poland, September 5-8, 1995, pp. 97-100.

[11]. EA 10/04 (EAL-G22) - *Uncertainty of Calibration Results in force Measurements,* European co-operation for Accreditation.

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