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ORIGINAL ARTICLE

Difference between calibration and practical force proving instruments

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Abstract

This is an experimental work on seventy load cells which aims to highlight the difference between results out of force, proving instruments calibration according to ISO 376:2011 and its practical use. It spots on the difference between the relative error of repeatability and reproducibility and their contributions on load cells classifications, uncertainty estimation and calibration time. Results show that there is no significant effect for relative error of repeatability on load cell classification, ignoring the relative repeatability error in estimating the relative expanded uncertainty lead to decrease with values between 1 ppm and 270 ppm in the range from 20 % to 50 % of load cell capacity and by values between 1 ppm and 183 ppm in the range from 50 % to 100 % of the load cell capacity. It is concluded that performing measurements to calculate the relative error of repeatability is not effective in the normal calibration process for the examined seventy load cells, further measurements over subsequent years are recommended to ensure results reproducibility aiming to generalize the conclusion and recommend measurements for the relative repeatability error for load cell conformity assessment after manufacturing.

Keywords: ISO 376; repeatability; reversibility; uncertainty; reproducibility

1. Introduction

Deadweight machines are the primary standards in force measurements [1]. Force calibration laboratories use different types of devices with different classes and uncertainties as force proving instruments. Precision load cells are used to disseminate traceability from primary standard to working standards through secondary and reference standards. Load cells represent one form of the electrical force proving instruments, and may be characterized as transfer or working standards based on their metrological characteristic [2]. Load cells are based on using special designed structures which perform elastically in a predictable and repeatable manner in relative to the applied force, which is translated into a voltage by the resistance change in the intimately bonded strain gages on the sensor structure. International standards and guides are used to specify load cell calibration procedures [3, 4, 5]. Force international committees work on developing procedures and techniques to extend and facilitate realization of force measurements to suit all applications [6, 7, 8, 9]. There is increase demand especially in Europe for forces up to 50 MN [10, 11]. Forces in in this range are measured using Build up systems [12, 13] and different researches are running on characterizing build up systems [13, 14, 15, 16, 17]. ISO 376 third edition [10] was cancelled and replaced by the fourth edition [3] which classifies load cells in four categories (A, B, C and D) based on their application principle. Different calibration sequence for case (A) and case (C) was defined by ISO 376:2011 rather than that for case (B) and case (D) as

Table 1: Relevant relative errors for each case according to ISO 376:2011.

Case	Relative error of					
	Reproducibility (b)	**Repeatability** (b')	**Interpolation** (f_c)	**Zero** (f_0)	**Reversibility** (v)	**Creep** (c)
A	□	□	—	□	—	□
B	□	□	—	□	□	—
C	□	□	—	□	—	□
D	□	□	—	□	□	—

shown in **Figure 1**. Also, 376:2011 defined different data analysis for Case (A) and (B) than that for cases (C) and (D) [3]. The content of the calibration certificate is determined based on the calibration sequence and the method by which calibration data was analyzed [3, 18]. **Figure 2** identify calibration process phases. The relevant relative errors per each load cell case have to be reported in the calibration certificate as per listed in **Table 1**. The relative errors of reproducibility, repeatability and zero are common in characterizing a load cell whatever its application case, as shown in Table 1.

2. Research roots

Relative error of reproducibility (b) and repeatability (b') are determined from the ascending forces applied on the load cell during calibration, and can be considered as indicators for the load cell precision under the applied force. The difference between reproducibility and repeatability is that repeatability represents the dispersion of output reading for repeated loading under identical loading; it is calculated from **Equation 1**, where $\overline{X}_{wr}$ is the average value of the response without rotation, X_1 and X_2 are the responses from the 1st and 2nd series (same position with respect to the machine loading axis, without rotation) respectively. On the other hand, reproducibility error represents the dispersion of output reading for repeated loads under changing loading conditions; it is calculated from **Equation 2**, where $X_{\max}$ and $X_{\min}$ are the maximum and the minimum responses from the ascending test forces (1st, 3rd and 5th series), and $\overline{X}_r$ is the average value of the responses with rotations with respect to the machine loading axis (1st, 3rd and 5th series).

$$b' = \left| \frac{X_2 - X_1}{\overline{X}_{wr}} \right| \cdot 100, \quad \text{where } \overline{X}_{wr} = \frac{X_1 + X_2}{2}, \tag{1}$$

$$b = \left| \frac{X_{\max} - X_{\min}}{\overline{X}_r} \right| \cdot 100, \quad \text{where } \overline{X}_r = \frac{X_1 + X_3 + X_5}{3}. \tag{2}$$

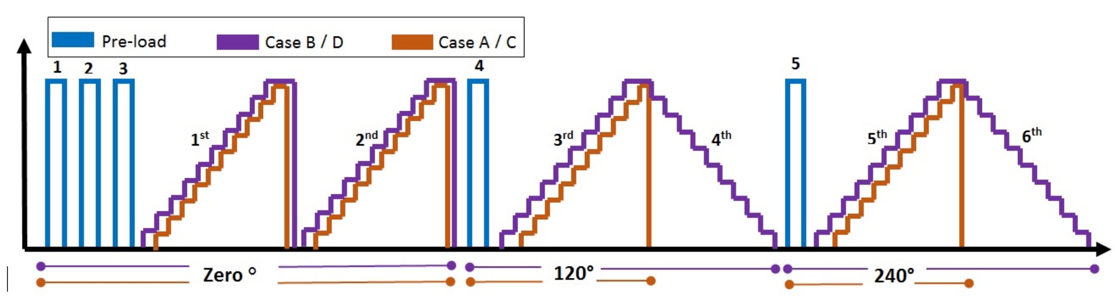

Figure 1: ISO 376:2011 Calibration sequence (cases A, B, C and D).

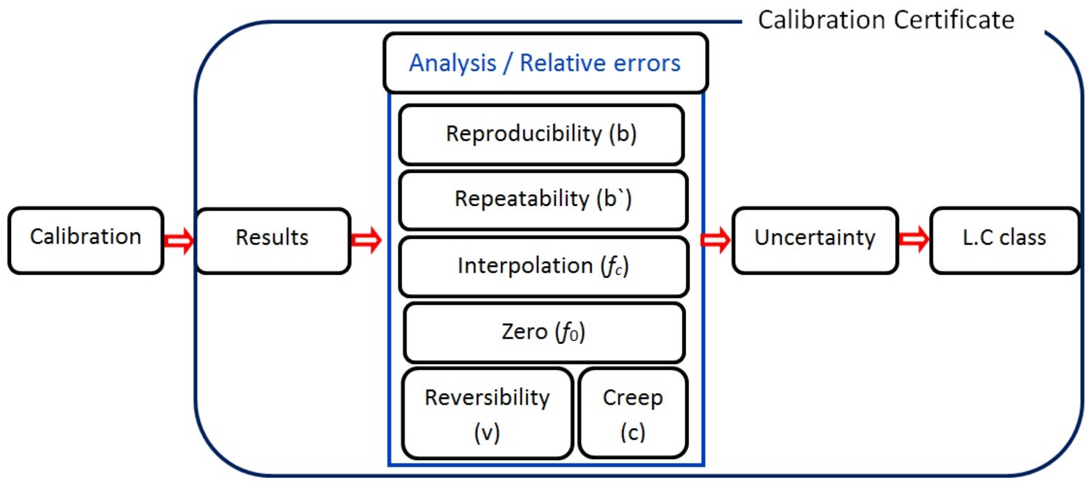

Figure 2: ISO 376:2011 Calibration outputs.

Figure 3 shows the effect of strain gauge inclination from the loading axis. **Equation 3** and **Equation 4** show the effect of the strain gauge application on the measured force values [19, 20] where: ε_1 and ε_2 are the strain at the principal axis, ε_0 is the strain at the S.G. bonding axis and θ is the inclination angle between the S.G. axis and force application axis. Rotating the load cell around the calibration machine loading axis permits eliminating the effect of parasitic effects [21] caused by different positioning; this effect is partially eliminated by suitable averaging.

$$\varepsilon_0 = \frac{1}{2}[(\varepsilon_1 + \varepsilon_2) - (\varepsilon_1 - \varepsilon_2)\cos 2\theta], \tag{3}$$

but since $\varepsilon_2 = -\nu\varepsilon_1$, it follows that

$$\varepsilon_0 = \frac{1}{2}\varepsilon_1[(1 - \nu) - (1 + \nu)\cos 2\theta]. \tag{4}$$

Small relative repeatability and reproducibility errors indicate good manufacturing techniques, while small repeatability error in relative to reproducibility error indicate constructional asymmetries in the load cell (design–machining Strain Gauge (S.G.)).

The relative error of repeatability is a result of calibration machine - load cell interaction, as the load cell is used by the user and interacts with another machine (different loading mechanism). Difference between the calibration machine and the user loading mechanism is reflected on

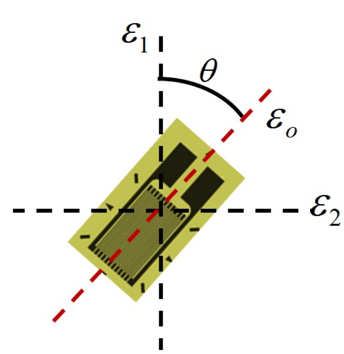

Figure 3: S.G. inclination angle effect on measured strain

machine –load cell interaction [22, 23], which indicates that repeatability cannot be considered as the characteristic determined during calibration, thus reproducibility is more appropriate [24]. This may reflect that reproducibility is more reliable, and repeatability is not an added value for the metrological characteristic during application.

3. Experimental work

The effect of the second series in the first mounting position on load cell classification, uncertainty estimation and calibration time was studied through experimental work on Seventy different load cells with nominal capacities range from 1 kN to 5000 kN, the load cells were calibrated on a primary (0.002 %) and secondary calibration machines (0.005 % to 0.01 %) according to ISO 376:2011 (increasing and decreasing) (**Figure 4a** and **Figure 4b**). Load cells were energized for 30 min before calibration. The response of the load cells was monitored at (23 ± 2) °C using HBM, DMP-40 indicator (0.000 001 mV/V). The calibration was performed at a temperature stable to within ±1 °C as per ISO 376:2011 recommendations.

4. Results

4.1. Results and load cell classification

Load cell are classified according to the magnitude of the relative errors shown in **Table 2**. The seventy load cells were classified in the ranges from 20 % to 50 % and from 20 % to 100 % of its nominal capacity. **Table 3** shows the classification of the seventy load cells and **Suppl. A** lists the seventy load cell capacities and their classification criteria, which are summarized in **Table 4**.

It is clear from Table 3 and Suppl. A that the load cell classification is developed as the classification range tends to maximum capacity. Thirty five load cell did not meet the metrological criteria for class (0) in the range from 20 % to 50 %, while twenty-eight load cell did not meet didn't met the metrological criteria for class (0) in the range from 50 % to 100 %.

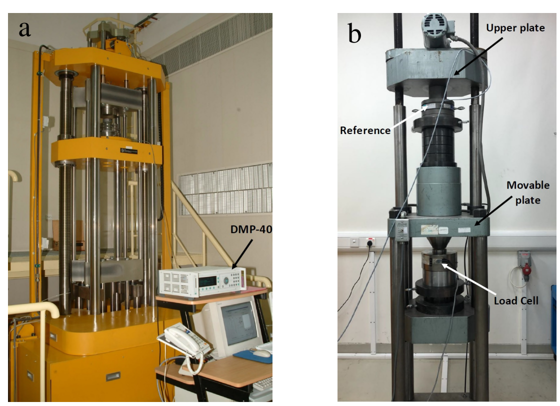

Figure 4: a NIS 500 kN DWM and b 1350 kN NIS universal loading.

Table 2: Characteristics of the force proving instruments according to ISO 376:2011

Class	Relative error of the force proving instrument %					
	Reproducibility	**Repeatability**	**Interpolation**	**zero**	**reversibility**	**Creep**
	b	b'	F_c	f_0	v	c
0	0.05	0.025	0.025	0.012	0.07	0.025
0.5	0.1	0.05	0.05	0.025	0.15	0.05
1	0.2	0.1	0.1	0.05	0.3	0.1
2	0.4	0.2	0.2	0.1	0.5	0.2

Table 4 shows that the repeatability (b') has no significant effect on classifying the seventy load cells, since it only contributes in classifying one load cell in the range from 20 % to 50 %, which was already classified for the same class based on reversibility (v) and interpolation error (f_c); it also contributes in classifying another load cell in the range from (50 % to 100 %), which was already classified for the same class based on zero error (f_0).

4.2. Results and uncertainty

Relative errors of repeatability and reproducibility contribute in estimating the combined relative uncertainty as detailed in Annex (c) in ISO 376:2011 [5]. **Equation 5** and **Equation 6** show contribution of the relative uncertainty of the reproducibility (w_b) and repeatability ($w_{b'}$) errors simultaneously [25]. Uncertainty due to reproducibility (w_b) is as result of averaging data at the three mounting positions, while uncertainty due to repeatability ($w_{b'}$) is calculated from the relative repeatability error (1st and 2nd loading series at the first mounting positions) and this is a machine –load cell interaction, as presented earlier. Each user has to estimate the machine –load cell interaction as a source in his/her own uncertainty budget. The uncertainty value of repeatability estimated during calibration for load cell calibration may be considered as an estimation source as each user has to estimate his/her own machine-load cell interaction.

$$w_b = \frac{1}{|\overline{X}_r|}\sqrt{\frac{1}{6}\left[\left(X_1+\overline{X}_r\right)^2+\left(X_3+\overline{X}_r\right)^2+\left(X_5+\overline{X}_r\right)^2\right]}, \tag{5}$$

$$w_{b'} = \frac{b^{'}}{100\sqrt{3}}. \tag{6}$$

The relative expanded uncertainty for the seventy load cells were calculated with and without the contribution of the relative repeatability error. Suppl. A shows the difference between estimating the expanded relative uncertainty with and without repeatability contribution.

Table 3: Classification of the seventy load cells (L.C) in the range from 20 % to 50 % and from 50 % to 100 %

Load cell class	**0**	**0.5**	**1**	**2**	**out of class**
Class in range 20 % to 50 %	35 L.C	19 L.C	4 L.C	4 L.C	8 L.C
Class in range 50 % to 100 %	42 L.C	16 L.C	3 L.C	4 L.C	5 L.C

Table 4: Classification criteria for the seventy load cells.

Range	b	b'	f_c	f_0	v	b, v	b, f_c	b', f_0	b', f_c, v	b, f_c, f_0	Total
20 % to 50 %	3	–	7	4	16	3	1	–	1	–	35
50 % to 100 %	5	–	6	4	10	–	1	1	–	1	28

It is clear that the relative expanded uncertainty decreases by values between 1 ppm and 1451 ppm in the range from 20 % to 50 % of load cell capacity and by values between 1 ppm and 437 ppm in the range from 50 % to 100 % of the load cell capacity. Comparing the relative expanded uncertainty after excluding the unclassified load cell shows that the relative expand uncertainty decreases by values between 1 ppm and 270 ppm in the range from 20 % to 50 % of load cell capacity, and by values between 1 ppm and 183 ppm in the range from 50 % to 100 % of the load cell capacity.

4.3. Results and calibration time

Calibration time differs from one machine to another according to the working principle (pure dead weight or amplification system or hydraulic system); for example NIS 5 MN force standard machine which was designed by GTM takes three hours to calibrate 5 MN load cell (the machine magnifies 500 kN pure dead weight to 5000 kN), NMCC 5 MN secondary force calibration machine, which was designed by Morehouse, takes 6 hours to calibrate 5 MN force transducer, while the biggest hydraulic force calibration machine in the world, the 60 MN machine at FJIM needs 2.5 h only.

As results of ignoring measurements required for calculating the relative error of repeatability; the second loading series in the first mounting position (zero position) as per ISO 376:2011 will be neglected. Neglecting the second loading series will reflect on decreasing the calibration time. Assuming that loading series time is the same as the unloading series time will lead to optimize calibration time for each load cell by 16.67 % of the loading series time, which reflects on the total calibration time. Meanwhile, the relative repeatability is a critical criterion in developing force transducers, as transducers sometimes may not meet the manufacturer's conditions due to deviations in material, strain gauge application or creep compensation elements of the transducers, which can be easily detected through measuring the relative repeatability error during the first calibration. Thus, measurements for relative repeatability error are recommended for load cells upon their manufacturing and before being placed to customers as a requirement for the conformity assessment.

5. Conclusion

Results of seventy load cells calibrated according to ISO 376:2011show that the repeatability (b') has no significant effect on classifying the force proving instruments. As the machine-load cell interaction (Relative error of repeatability) was ignored during calibration result analysis, it decreases the relative expanded uncertainty for the seventy load cells by values between 1 ppm and 270 ppm in the range from 20 % to 50 % of load cell capacity and by values between 1 ppm and 183 ppm in the range from 50 % to 100 % of the load cell capacity. Ignoring performing the repeatability measurements (the second loading series in the first mounting position as per ISO 376:2011) during the calibration process decreased the calibration time by 16.67 % of the loading series time.

It is recommended to limit performing the second loading series in the first mounting position (repeatability measurements series) and relevant calculations for the first calibration before being placed in the market (conformity assessment), and ignore performing repeatability measurements and relevant calculation in periodic calibrations and commercial applications, and inform users to estimate the uncertainty results from their own machine-load cell interaction.

6. Future work

Further measurements are required to ensure the results of these measurements. First, to perform the previous experimental work on load cells starting from 5 MN as the behavior of the force transducers may not be similar to the range (1 kN to 5000 kN) investigated in this work due to physical effects inside the material. Second, to reproduce these measurements on selected thirty-five load cells out of these seventy load cells. The selected load cells must represent all classes. Additionally, the selected load cells must be measured and examined over subsequent three years and changes in the results have to be expressed and illustrated briefly in order to ensure probability to generalize the conclusion.

References

[1] Kumar H, Sharma C, Kumar A, Arora PK. Retrospective Investigations of Force Measurement, *MAPAN-Journal of Metrology Society of India*, 30(4): 291-302, 2015.

doi: 10.1007/s12647-015-0148-y

[2] Osman Seif, Kumme R, El–Hakeem H, Löffler F, Hasan E, Ragaie Rashad M, Kouta F. Multicapacity load cell prototype, *Acta IMEKO*, 5(3):64-69, 2016.

doi: 10.21014/acta_imeko.v5i3.310

[3] ISO 376:2011, Metallic materials-Calibration of force proving instruments used for the verification of uniaxial testing machines. 2017

https://www.iso.org/standard/44661.html

[4] ASTM E74-18, Standard Practices of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines. 2018

https://www.astm.org/Standards/E74

[5] OIML R60:2013, Metrological Regulation for Load Cells. 2017

http://celuladecarga.com.br/17/wp-content/uploads/2017/08/OIMLR60.pdf

[6] Kumar H, Pardeep, Kaushik M, Kumar A. Development and Characterization of a Modified Ring Shaped Force Transducer, *MAPAN- Journal of Metrology Society of India*, 30(1):37-47, 2015.

doi: 10.1007/s12647-014-0118-9

[7] Tegtmeier F, Gutsch W. Calibration of a 30 MN Material Testing Machine According to ISO 7500- 1 Using a Force-Transducer Build-Up System, *Journal of Physics*, Conference Series 1065, 2018.

doi: 10.1088/1742-6596/1065/4/042018

[8] Kumme R, Tegtmeier F, Röske D, Barthel A, Germak A, Averlant P. Force Traceability Within the Meganewton Range, *XXII World Congress Metrology, IMEKO*, Cape Town, Republic of South Africa, 2014.

https://www.imeko.org/publications/tc3-2014/IMEKO-TC3-2014-027.pdf

[9] Nobakht N, Askari M, Nikbakht A M, Ghorbani Z. Development of a Dynamometer to Measure All Forces and Moments Applied on Tillage Tools, *MAPAN- Journal of Metrology Society of India*, 32(4):311-319, 2017.

doi: 10.1007/s12647-017-0221-9

[10] European Metrology Research Programme (EMRP). 2008.

http://www.emrponline.eu/

[11] Medina N. Validity of extrapolation based on polynomial approximations, *XXII World Congress Metrology, IMEKO*, Helsinki, Finland, 2017.

https://www.imeko.org/publications/tc3-2017/IMEKO-TC3-2017-005.pdf

[12] Ferrero C, Marinari C, Martino E. Development and metrological characterization of a build-up force standard up to 3 MN, *XVII World Congress Metrology, IMEKO*, Dubrovnik, Croatia, 2003.

https://www.researchgate.net/profile/C_Marinari/publication/242293836

[13] Wei L, Xiao-xiang Y, Jinhui Y. Rotation effects of force transducer on the output of the build-up system, *Measurement-Journal of the International Measurement Confederation*, 138:659-671, 2019.

doi: 10.1016/j.measurement.2019.01.071

[14] Tieping W, Xiao-xiang Y, Jinhui Y, Hang X. The influence of a balanced structure on the rotation effect of a build-up system, *Measurement-Journal of the International Measurement Confederation*, 61:162-168, 2015.

doi: 10.1016/j.measurement.2014.10.043

[15] Tegtmeier F, Röske D, Liang W. Practical Applications of an Enhanced Uncertainty Model For Build-Up Systems, *XXIII World Congress Metrology, IMEKO*, Helsinki, Finland, 2017.

https://www.imeko.org/publications/tc3-2017/IMEKO-TC3-2017-012.pdf

[16] Liang W, Yang X, Yao J, Tegtmeier F. Investigation The Creep and Creep Recovery Behavior of Build-Up Systems, *XXIII World Congress Metrology, IMEKO* Helsinki, Finland, 2017.

https://www.imeko.org/publications/tc3-2017/IMEKO-TC3-2017-036.pdf

[17] Brodyagin SV, Patokin EV. An experimental investigation of the error in measurement of a force by a group of dynamometers situated in parallel, *Measurement Techniques*, 51(6):627-631, 2008.

doi: 10.1007/s11018-008-9091-4

[18] Toshiyuki H, Kazunaga U. Experimental Verification of the Evaluation Method of Creep Uncertainty from Reversibility Error Prescribed in ISO 376:2011, *55th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE)*, Tsukuba, JAPAN, 2016.

doi: 10.1109/SICE.2016.7749176

[19] Hoffmann K. Applying the Wheastone Bridge Circuit, Hottinger Baldwin Messtechnik GmbH. Germany 2011.

http:// www.Hbm.com.

[20] Hoffmann K. An Introduction to stress analysis and transducer design using strain gauges, Hottinger Baldwin Messtechnik GmbH, Germany.

http:// www.Hbm.com.

[21] Ferrero C. The measurement of parasitic components in national force standard machines, *Measurement- Journal of the International Measurement Confederation*, 8(2):66-76,1990.

doi: 10.1016/0263-2241(90)90028-5

[22] Park Y Sawi M, Osman S, Titus S, Lee M. Final report on force key comparison APMP.M.F-K2.a and APMP.M.F-K2.b (50 kN and 100 kN), *Metrologia, 56(1A),Tech Supplement*, 2019.

http://iopscience.iop.org/article/10.1088/0026-1394/49/1A/07002/meta

[23] Kumme R, Averlant P, Bartel T, Germak A, Knott A, Park Y, Roske D. Final report on the force key comparison CCM.F-K3, *Metrologia*, *56(1A), Tech Supplement*, 2019.

doi: 10.1088/0026-1394/56/1A/07001

[24] Bray A, Barbato G, Levi R. Theory and practice of force measurement, Academic press limited, London 1990, ISBN:0-12-128453-0.

[25] EURAMET Cg-4, *Uncertainty of Force Measurements*, Calibration guide, Version 2.0 (03/2011).

https://www.euramet.org/Media/docs/Publications/calguides/EURAMET_cg-4__v_2.0_ Uncertainty_of_Force_Measurements.pdf

Diferencia entre calibración y uso práctico de instrumentos para medición de fuerza

Resumen: Este es un trabajo experimental realizado sobre setenta celdas de carga, que apunta a resaltar la diferencia entre los resultados de la calibración de instrumentos para medición de fuerza de acuerdo con la norma ISO 376:2011 y su uso práctico. Se determina la diferencia entre el error relativo de repetibilidad y reproducibilidad y sus contribuciones en la clasificación de celdas de carga, estimación de incertidumbre y tiempo de calibración. Los resultados muestran que no existe un efecto significativo del error relativo de repetibilidad en la clasificación de celdas de carga, ignorando que el error relativo de repetibilidad produjo una disminución en la estimación de la incertidumbre expandida relativa, con valores entre 1 ppm y 270 ppm en el rango desde 20 % a 50 % de la capacidad de la celda de carga, y valores entre 1 ppm y 183 ppm en el rango desde 50 % a 100 % de la capacidad de la celda de carga. Se concluye que realizar mediciones para calcular el error relativo de repetibilidad no es efectivo en el proceso normal de calibración para las setenta celdas de carga examinadas, y se recomiendan mediciones adicionales en años subsiguientes para asegurar la reproducibilidad de resultados apuntando a generalizar la conclusión y recomendar mediciones del error relativo de repetibilidad para la evaluación de conformidad de las celdas de carga luego de su fabricación.

Palabras Clave: ISO 376; repetibilidad; reversibilidad; incertidumbre; reproducibilidad.

Diferença entre calibração e uso prático de instrumentos para a medição de força

Resumo: Este é um trabalho experimental realizado com setenta células de carga, que objetiva demonstrar a diferença entre os resultados da calibração de instrumentos para medição de força de acordo com a norma ISSO 376:2011 e seu uso prático. Identifica a diferença entre o erro relativo de repetibilidade e reprodutibilidade e suas contribuições nas classificações das células de carga, estimativa da incerteza e tempo de calibração. Os resultados mostram que não existe um efeito significativo para o erro relativo de repetibilidade na classificação das células de carga, ignorando que o erro relativo de repetibilidade na estimativa da incerteza expandida relativa leva a diminuição, com valores entre 1 ppm e 270 ppm na faixa de 20 % a 50 % da capacidade da célula de carga, e valores entre 1 ppm y 183 ppm na faixa de 50 % a 100 % da capacidade da célula de carga. Conclui-se que realizar medições para calcular o erro relativo de repetibilidade não é efetivo no processo normal de calibração para as setentas células de carga examinadas, e se recomendam medições adicionais em anos subsequentes para garantir a reprodutibilidade dos resultados buscando generalizar a conclusão e recomendar medições para o erro de repetibilidade relativo para avaliação da conformidade da célula de carga após a fabricação.

Palavras-chave: ISO 376; repetibilidade; reversibilidade; incerteza; reprodutibilidade.

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