

Proposed approach for force transducers classification

Gouda M. Mahmoud^{*}, Seif M. Osman, and Riham S. Hegazy

National Institute for Standards (NIS), Giza, Egypt

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Abstract. In accordance with the recent version of ISO 376:2011, the classification of the force transducers is based on the relative errors calculated from the calibration results. This classification approach doesn't take the uncertainty of measurement into consideration. It becomes one of the most important factors that must be utilized when making a classification decision based on of ISO/IEC 17025:2017. In this study a proposed approach for force proving instrument classification was developed. This approach is based on taking into account the calibration results uncertainty of the instruments as a decision rule for classifications. Since the expanded budget uncertainty is a combination of different parameters that may affect the classifications decisions so it is more realistic and more accurate for decision making. The results of this paper demonstrate a recommendation for ISO 376:2011 to modify its classification criteria for the force proving instruments in the upcoming version of this standard.

Keywords: Uncertainty / decision rule / compliance statement / force proving instruments / classifications

1 Introduction

In various applications in industry, performing measurements are mandatory activities to evaluate the critical parameters of the products or items. It is necessary to estimate the compressive load tensile forces, dimension qualifications, chemical analysis, etc. These applications can be utilized in testing of materials, industrial weighing, spare parts measurements [1]. In all measurements and applications, there will be an uncertainty estimation for the measured parameter. For force measurements, the devices utilized to conduct the measurements must be traceable to a realization of the SI unit of the forces, within this claimed uncertainty. Force proving instrument (force transducer) is to be used either to calibrate industrial force transducer or to measure forces directly, such as this one inserted in the tensile testing machines. Those force transducers have to be traceable to the national force standard machines which have recognized calibration measurement capabilities (CMC) [2].

The calibration methods for calibrating those force proving instruments will generally be performed in accordance with a documented procedure, such as ISO376:2011 [3]. This documented calibration procedure has identified the classification criteria for the force proving instruments based on various relative errors such as

relative reproducibility and repeatability errors, relative interpolation error, relative zero error, relative reversibility error and relative creep error [4]. Since this classification is considered as a conformity statement like Pass/Fail, In Tolerance/Out of Tolerance, In Spec/Out of Spec which is considered as compliance or noncompliance identifications with a relevant standard, specifications or requirements [5]. As per ISO 17025:2017 "The laboratory shall report the statement of conformity based on predefined decisions rules. These decision rules describe how measurement uncertainties are taken into consideration when providing conformance with specific requirement. Guidelines on Decision Rules and Statements of Conformity ILAC G8:09:2019 identify the different cases in conformity statement identification [6]. The objective of this manuscript is to harmonize the requirements of ISO 17025:2017 regarding the decision rules and utilizing uncertainty in classification decision making and the upcoming version of ISO 376 for force proving instrument calibrations and to demonstrate a recommend proposal to take into account the uncertainty budget instead of different error as a bases for classifications.

ISO 376:2011 for Calibrations of force-proving instruments relays only on relative errors as criterion for classifications. The classifications of the force transducers are a type of conformity statement providing and decisions rules have to be identified for this classification [7]. In accordance with the recent released version of the standard of accreditation ISO/IEC 17025:2017 it is required to

^{*} Corresponding author: goudamohamed15@yahoo.com

Table 1. Classification criteria mentioned in ISO 376:2011.

Class	Relative error of the force-proving instrument (%)						Expanded uncertainty of applied calibration force (95% level of confidence) (%)
	Reproducibility [®]	Repeatability (R')	Interpolation (i _c)	Zero (z ₀)	Reversibility (v)	Creep (c)	
0	0.05	0.025	±0.025	±0.012	0.07	0.025	±0.01
0.5	0.10	0.05	±0.050	±0.025	0.15	0.050	±0.02
1	0.20	0.10	±0.100	±0.050	0.30	0.100	±0.05
2	0.40	0.20	±0.200	±0.100	0.50	0.200	±0.10

identify the decision rules for conformity statement and these decisions rules have to take into account the budget uncertainty as a base of determine the statue of the conformity. Since ISO 376:2011 relays only on the relative errors to make the classification decision and doesn't rely on the uncertainty so there is a clear conflict between ISO 376:2011 and the newly released standard of accreditation ISO/IEC 17025:2017 [8]. In accordance with ISO 376:2011, the relative errors have to be calculated using equations from 1 to 10 and compared with the values mentioned in Table 1 and the class will be identified according to the highest error value (worst case will be the overall class).

To resolve this conflict, consideration has been given to conduct this study. The aim of this article is to present a proposed classifications criterion for the force proving instruments. This proposal is aimed to be millstone for standards ISO 376:2011 as a base for modifying the classifications criterion for the upcoming issue of this standard and to be in line with ISO/IEC 17025:2017 and the international re equipments for conformity statements providing such as ILAC G8:09/2019 guideline on decisions Rules and conformity of statement [9].

To consider the risk in conformity statement there are three basic risks related to the uncertainty approach through making conformity or compliance decisions for calibration results which are required to meet specification, standards and regulatory limits. Conformity decision rules can then be applied accordingly.

In brief, they are, risk of false acceptance of a test result, risk of false rejection of a test result and shared risk.

The fundamental of the decision rule is to identify an "Acceptance zone" and a "Rejection zone", such that if the measurement result lies in the acceptance zone, the item is declared compliant, and, if it is in the rejection zone, it is declared non-compliant [10]. Hence, a decision rule documents the method of determining the location of acceptance and rejection zones, ideally including the minimum acceptable level of the probability that the value of the targeted values in between the specified limits. A simple decision rule that is widely used today is in a situation where a measurement implies non-compliance with an upper or lower specification limit if the measured value exceeds the limit by its expanded uncertainty, U [11].

2 Mathematical background for ISO 376:2011 classification

In accordance with ISO 376:2011 the force proving instruments have to be classified from 20% to 100% of the maximum nominal capacity of the force proving instruments and these classifications are based on the highest value of the relative errors of difference relative errors identified below. The estimation of those parameters are calculated using equations from 1 to 10 and the class decision will be based on the highest value in the calculated relative error. These parameters will be identified as follow;

2.1 The reproducibility and repeatability errors, R and R'

These errors are calculated for all calibrations forces values and in both cases, i.e. with rotation of the force-proving instrument (R) and without rotation (R'), using the following equations [12].

$$R = \left| \frac{x_{\max} - x_{\min}}{\bar{X}_r} \right| \quad (1)$$

where:

x_{\max} : Maximum deflection from loading trails 1, 3 and 5 indicated in Figure 1,

x_{\min} : Minimum deflection from loading trails 1, 3 and 5 indicated in Figure 1,

where:

$$\bar{X}_r = \frac{x_1 + x_3 + x_5}{3} \quad (2)$$

$$R' = \left| \frac{x_2 - x_1}{\bar{X}_{wr}} \right| \times 100 \quad (3)$$

And:

$$\bar{X}_{wr} = \frac{x_1 + x_2}{2} \quad (4)$$

\bar{X}_r : Average value of the deflections with rotation,

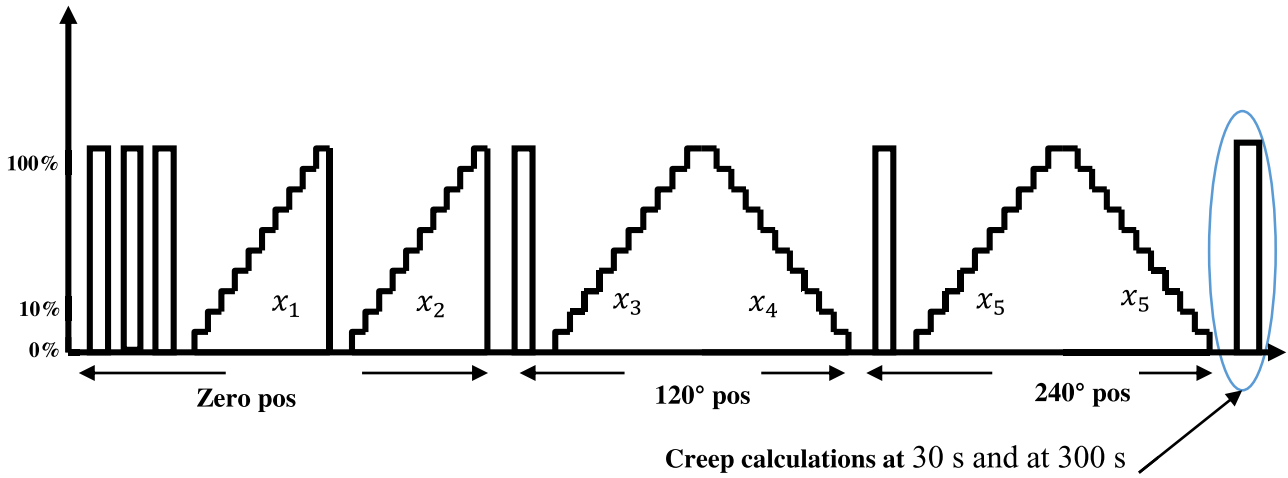


Fig. 1. Calibration procedure and series as per ISO 376:2011.

\bar{X}_{wr} Average value of the deflections without rotation. where x_1, x_2, x_3, x_5 are the response of the force proving instruments at increasing mode, x_4 and x_6 are the response of the force proving instruments at decreasing mode as per Figure 1.

2.2 The interpolation error, i_c

This error is determined using a first-, second- or third-degree equation giving the deflection X_r as a function of the calibration force. The relative interpolation error shall be calculated from the following equation [12]:

$$i_c = \frac{\bar{X}_r - x_a}{x_a} \times 100 \quad (5)$$

x_a : Computed value of deflection obtained from the curve fitting of the calibration results.

2.3 Zero error, z_0

The zero reading shall be recorded before and after each series of tests. The zero reading shall be taken approximately 30 s after the force has been completely removed. The relative zero errors are calculated from the equation:

$$z_0 = \frac{i_r - i_o}{X_N} \times 100 \quad (6)$$

i_r : Reading on the indicator after removal of force,

i_o : Reading on the indicator before application of force,

X_N : Maximum calibration force.

2.4 The reversibility errors, v

The relative reversibility errors are determined at each calibration. It can be calculated as the divergence between the response at increasing forces and decreasing forces. The

relative reversibility error to be calculated using the following equations [12]:

$$v_1 = \left| \frac{x_4 - x_3}{x_3} \right| \times 100 \quad (7)$$

$$v_2 = \left| \frac{x_6 - x_5}{x_5} \right| \times 100 \quad (8)$$

Where v is calculated as the mean value of v_1, v_2 :

$$v = \frac{v_1 + v_2}{2} \quad (9)$$

2.5 The creep error, c

It calculates as the divergence in response i_{30} obtained at 30 s and i_{300} obtained 300 s after the application or removal of the maximum calibrated force:

$$c = \left| \frac{i_{300} - i_{30}}{X_N} \right| \times 100 \quad (10)$$

The contribution of this item is the maximum relative creep error evaluated.

3 Experimental set-up and calibration procedure

A load cell of 1000 kN force transducer (series K T N-D, GTM manufactured) (see Fig. 2) was used, and it was calibrated by 1000 kN standard dead weights machine (GTM Manufactured, see Fig. 3). This machine is internationally recognized by BIPM with uncertainty of $\pm 0.01\%$.

The results of 1000 kN force transducer were monitored by DMP40-digital-precision-measuring-amplifier (HBM



Fig. 2. 1000 kN Force transducer.



Fig. 3. DMP40 amplifier used in the experimental work.



Fig. 4. Standard dead weights machine used (1000 kN).

manufactured, see Fig. 4) with resolution of 0.000001 mv/v to get the best performance and the highest accuracy and better uncertainty.

Before calibration preloading is required by applying the maximum force to the instrument three times. The duration of each preload has to be from 60 to 90 s. The

calibration is conducted by applying two series of calibration forces to the force-proving instrument with increasing values only, without rotating the device. Then apply at least two further series of increasing and, if the force-proving instrument is to be calibrated in an increasing/decreasing loading direction, decreasing values. Between each of the further series of forces, rotate the force-proving instrument symmetrically on its axis to positions uniformly distributed over 360° (i.e. 0°, 120°, 240°), see Figure 1.

In accordance with ISO 376:2011, the classifications criterion of the forces proving instruments are described in the following table, refer to Table 1.

4 Statistical analysis

The combined uncertainty is calculated using the below equation:

$$u_c = \sqrt{\sum_{i=1}^8 u_i^2} \quad (11)$$

where: u_i (for $i=1:8$) are the following uncertainty components:

u_1 is the reproducibility relative standards uncertainty,
 u_2 is the repeatability relative standards uncertainty,
 u_3 is the interpolation relative standards uncertainty,
 u_4 is the drift in indicators zero output relative standards uncertainty

u_5 is the reversibility relative standards uncertainty,
 u_6 is the creep relative standards uncertainty
 u_7 is the indicator resolution relative standards uncertainty,
 u_8 is the applied loads relative standards uncertainty.

4.1 Estimating contributions of reproducibility uncertainty

u_1 can be calculated by the following equation, expressed in relative value:

$$u_1 = \frac{R}{100 \times \sqrt{3}} \quad (12)$$

4.2 Estimating contributions of repeatability uncertainty

u_2 is the uncertainty contribution due to the repeatability of the measured deflection, expressed in relative value:

$$u_2 = \frac{R'}{100 \times \sqrt{3}} \quad (13)$$

4.3. Estimating contributions of interpolation uncertainty

The component is the difference between the mean measured deflection and the value calculated from the interpolation equation:

$$u_3 = \left| \frac{\bar{x}_r - x_a}{\bar{x}_r} \right| \quad (14)$$

4.4 Estimating contributions of zero drift uncertainty

This uncertainty component is due to the fact that the force proving instrument's zero output can vary between measurement series and that the measured deflections could be a function of the time spent at zero force between series. This influence is not included in reproducibility because, generally, this time will be the same for all measurement series. One measure of this variation is the zero error, z_0 , so this effect can be estimated as follows:

$$u_4 = \frac{z_0}{100}. \quad (15)$$

4.5 Estimating contributions of reversibility uncertainty

The relative reversibility error is determined at each calibration, by carrying out a verification with increasing forces and then with decreasing forces:

$$u_5 = \frac{v}{100 \times \sqrt{3}}. \quad (16)$$

4.6 Estimating contributions of creep uncertainty

This uncertainty component is due to the fact that, at a given load, the measured response could be affected by the history of the previous short-term loading. One measure of this effect is the change in transducer output in the period from 30 to 300s after application or removal of the maximum calibration load. This effect could be evaluated as follows:

$$u_6 = \frac{c}{100 \times \sqrt{3}} \quad (17)$$

4.7 Estimating contributions of resolution uncertainty

At each point the results are obtained from two readings (the reading with an applied load minus the reading at zero load). Because of this, the resolution of the amplifier requires to be included twice as two rectangular distributions, each with a standard uncertainty of $r/(2\sqrt{3})$, where

r is the resolution, expressed in relative value:

$$u_7 = \frac{r}{\sqrt{12}}. \quad (18)$$

4.8 Estimating contributions of calibration force uncertainty

u_8 is the uncertainty of the applied loads by the calibration machines or dead weights machines on the force proving instruments (deadweights machine uncertainty it can be obtained from the technical specification or deadweight calibration certificates).

4.9 Estimation expanded and combined uncertainty

As per GUM and ISO 376:2011, for each calibrated point, evaluate the standard combined uncertainty (u_c). Where u_c is calculated as the square root for the sum of the squares for the previously estimated parameter contributions and this can be calculated using equation (11). The expanded uncertainty can be evaluated by multiply u_c by the coverage factor ($k=2$) at the relevant confidence level (95%) using equation (19).

$$U_{exp} = k * u_c \quad (19)$$

5 The proposed approach for classification

The main objective of this proposed approach is to classify the force measuring devices logically, realistically and accurately, taking into account all factors that may affect the classification decision making. This will be done by calculating the expanded budget uncertainty of all the influencing factors and thus ensuring the conformity between the ISO 376 and the international standard for accreditation as well as the international requirements. Throughout this proposal, the relative errors values calculated in Table 2 were used. These values were used to calculate the budget uncertainty at each class. All the influencing factors were combined with the percentage of their contribution in the expanded uncertainty to re-determine the classification process based on the uncertainties calculated and not on the relative error values (see Tab. 1). The international standard ISO 376:2011 identifies the uncertainty components calculated in equations from 12 to 18 there uncertainty values was mentioned in Table 2.

6 Results and discussion

Equation (19) was used to calculate the expanded uncertainty, then the value of the expanded uncertainty was multiplied by the value of the coverage factor 2, taking into account the 95% confidence level.

The proposed approach is based on utilizing the calibration results uncertainty of the force proving instruments as decision rule for the instruments classifications to be in line with ISO/IEC 17025:2017. The budget

Table 2. Uncertainty components evaluation utilized for the proposed approach.

Class	Relative uncertainty of the force-proving instrument (%)							Deadweights machine uncertainty (%)
	Reproducibility u_1	Repeatability u_2	Interpolation u_3	zero u_4	Reversibility u_5	Creep u_6	Resolution u_7	
0	0.000289	0.000144	0.025	0.00012	0.000404	0.000144	0.007217	0.005
0,5	0.000578	0.000289	0.050	0.00025	0.000866	0.000289	0.014434	0.010
1	0.001155	0.000577	0.100	0.0005	0.001732	0.000577	0.028868	0.025
2	0.002309	0.001155	0.200	0.0010	0.002887	0.001155	0.057735	0.050

Table 3. New expanded uncertainty.

Class	The combined uncertainty for all parameters %	Expanded uncertainty of the force proving instruments (95% level of confidence) (U_{exp}) %
0	0.026503	0.053005
0.5	0.053006	0.106012
1.0	0.107068	0.214136
2.0	0.214128	0.428255

Table 4. Proposed classification criteria.

Class	Expanded uncertainty of the force proving instruments (95% level of confidence and $k=2$)
0	0.05
0.5	0.10
1	0.25
2	0.50

uncertainty should be estimated and each component of uncertainty has to be calculated. Equation from (12)–(18) were used to calculate each standards uncertainty component. The combined uncertainty shall be calculated using equation (11). Table 2 summarized the uncertainty parameters mentioned as individual.

If the expanded uncertainties values are approximated to two significant figures so the results will be shown below in Table 4; Base on the proposed results mentioned in Table 3. The classifications criterion could be expressed in Table 4. The budget expanded uncertainty of the force proving instrument was estimated using equations mentioned above where it is the equivalent to all the contributed. It was found that it is possible to set corresponding values for each class as the values of the uncertainty in Table 4 is calculated from all the contributed components, the uncertainty values can be considered corresponding to each class and it is the limit for each class. Thus, there becomes a match between the

standard ISO 17025:2017 and ISO 376:2011, see Table 5, the results of the expanded uncertainty were expressed in two significant digits.

7 Conclusions

Recently for metrologist uncertainty is became the major factor in many of the decision situations that arise nowadays in metrology and measurement. Base on this principle the recent issued ISO/IEC 17025 specified a condition that the value of uncertainty has to be the decision rule for decision making such as classification, in tolerance out of tolerance, pass or fail ... etc.

In this paper the authors demonstrate a starting point to review the classification criterion mentioned in ISO 376:2011. In this article a recommendation for classification of the force proving instrument was proposed based on the uncertainty of the measurements. This proposal was raised to harmonize the classification criterion of the upcoming version of ISO 376 for force proving instrument calibration to be in line with ISO/IEC 17025 requirements. From this study it can be concluded that the values of expanded uncertainty can be used as the only factor in classifying force measuring devices, Since uncertainty budget is the combination of various components of that may affect the reported results of the instruments so it is more realistic and more comprehensive to be the decision rule for classification of these devices.

The proposal presented in this article was to provide a recommendation for classifying the force proving instruments. The proposed classifications criterion has to take

Table 5. Boundaries for force proving instruments for ISO 376 compared with the new proposed approaches.

Class	Classifications criterion based on ISO 376:2011							Proposed Classifications criterion Expanded uncertainty of the force proving instruments calibration (95% level of confidence) $\pm\%$
	Relative error of the force-proving instrument (%)							
	R	R'	i_c	z_0	v	c	U_{ref} (for Deadweights)	
0.0	0.050	0.025	0.025	± 0.012	0.070	0.025	± 0.010	0.050
0.5	0.100	0.050	0.050	± 0.025	0.150	0.050	± 0.020	0.100
1.0	0.200	0.100	0.100	± 0.050	0.300	0.100	± 0.050	0.250
2.0	0.400	0.200	0.200	± 0.100	0.500	0.200	± 0.100	0.500

into consideration the calibration results uncertainty budge.

This proposal is very important for force proving instruments manufacturers as it presents the importance of uncertainty in classification to declare the level of quality. The uncertainty estimated takes into account all the factors that may affect. This proposed approach is important for metrologists as well in terms of increasing the ability to consider all the factors that affect the force measurement, which is what was recommended to be taken into account during this article.

As a future work based on this investigation a conformity statement base risk at different risk situations such as customer risks and producer risks may investigated separately.

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