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Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines

Matériaux métalliques — Étalonnage des instruments de mesure de force utilisés pour la vérification des machines d'essais uniaxiaux

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 376 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

This fourth edition cancels and replaces the third edition (ISO 376:2004), which has been technically revised (for details, see the introduction).

Introduction

An ISO/TC 164/SC 1 working group has developed procedures for determining the measurement uncertainty of force-proving instruments, and these procedures have been added to this fourth edition as a new annex (Annex C).

In addition, this fourth edition allows the calibration to be performed in two ways:

- with reversible measurement for force-proving instruments which are going to be used with increasing and decreasing forces;
- without reversible measurement for force-proving instruments which are going to be used only with increasing forces.

In the first case, i.e. when the force-proving instrument is going to be used for reversible measurements, the calibration has to be performed with increasing and decreasing forces to determine the hysteresis of the force-proving instrument. In this case, there is no need to perform a creep test.

In the second case, i.e. when the force-proving instrument is not going to be used for reversible measurements, the calibration is performed with increasing forces only but, in addition, a creep test has to be performed. In this case, there is no need to determine the hysteresis.

Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines

1 Scope

This International Standard specifies a method for the calibration of force-proving instruments used for the static verification of uniaxial testing machines (e.g. tension/compression testing machines) and describes a procedure for the classification of these instruments.

This International Standard is applicable to force-proving instruments in which the force is determined by measuring the elastic deformation of a loaded member or a quantity which is proportional to it.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
force-proving instrument
whole assembly from the force transducer through to, and including, the indicator

4 Symbols and their designations

Symbols and their designations are given in Table 1.

Table 1 — Symbols and their designations

Symbol	Unit	Designation
b	%	Relative reproducibility error with rotation
b'	%	Relative repeatability error without rotation
c	%	Relative creep error
F_f	N	Maximum capacity of the transducer
F_N	N	Maximum calibration force
f_c	%	Relative interpolation error
f_0	%	Relative zero error
i_f	—	Reading[a] on the indicator after removal of force
i_o	—	Reading[a] on the indicator before application of force
i_{30}	—	Reading[a] on the indicator 30 s after application or removal of the maximum calibration force
i_{300}	—	Reading[a] on the indicator 300 s after application or removal of the maximum calibration force
r	N	Resolution of the indicator
v	%	Relative reversibility error of the force-proving instrument
X	—	Deflection with increasing test force
X_a	—	Computed value of deflection
X'	—	Deflection with decreasing test force
X_max	—	Maximum deflection from runs 1, 3 and 5
X_min	—	Minimum deflection from runs 1, 3 and 5
X_N	—	Deflection corresponding to the maximum calibration force
$\overline{X}_\mathrm{r}$	—	Average value of the deflections with rotation
$\overline{X}_\mathrm{wr}$	—	Average value of the deflections without rotation

[a] Reading value corresponding to the deflection.

5 Principle

Calibration consists of applying precisely known forces to the force transducer and recording the data from the indicator, which is considered an integral part of the force-proving instrument.

When an electrical measurement is made, the indicator may be replaced by another indicator and the force-proving instrument need not be recalibrated provided the following conditions are fulfilled.

a) The original and replacement indicators have calibration certificates, traceable to national standards, which give the results of calibration in terms of electrical base units (volt, ampere). The replacement indicator shall be calibrated over a range equal to or greater than the range for which it is used with the force-proving instrument, and the resolution of the replacement indicator shall be at least equal to the resolution of the original indicator when it is used with the force-proving instrument.

b) The units and excitation source of the replacement indicator should be respectively of the same quantity (e.g. 5 V, 10 V) and type (e.g. AC or DC carrier frequency).

c) The uncertainty of each indicator (both the original and the replacement indicators) shall not significantly influence the uncertainty of the whole force-proving instrument assembly. It is recommended that the uncertainty of the replacement indicator be no greater than 1/3 of the uncertainty of the entire system (see C.2.11).

6 Characteristics of force-proving instruments

6.1 Identification of the force-proving instrument

All the elements of the force-proving instrument (including the cables for electrical connection) shall be individually and uniquely identified, e.g. by the name of the manufacturer, the model and the serial number. For the force transducer, the maximum working force shall be indicated.

6.2 Application of force

The force transducer and its loading fittings shall be designed so as to ensure axial application of force, whether in tension or compression.

Examples of loading fittings are given in Annex A.

6.3 Measurement of deflection

Measurement of the deflection of the loaded member of the force transducer may be carried out by mechanical, electrical, optical or other means with adequate accuracy and stability.

The type and the quality of the deflection measuring system determine whether the force-proving instrument is classified only for specific calibration forces or for interpolation (see Clause 7).

Generally, the use of force-proving instruments with dial gauges as a means of measuring the deflection is limited to the forces for which the instruments have been calibrated. The dial gauge, if used over a long travel, may contain large localized periodic errors which produce an uncertainty too great to permit interpolation between calibration forces. The dial gauge may be used for interpolation if its periodic error has a negligible influence on the interpolation error of the force-proving instrument.

7 Calibration of the force-proving instrument

7.1 General

7.1.1 Preliminary measures

Before undertaking the calibration of the force-proving instrument, ensure that this instrument is able to be calibrated. This can be done by means of preliminary tests such as those defined below and given as examples.

7.1.2 Overloading test

This optional test is described in Clause B.1.

7.1.3 Verification relating to application of forces

Ensure

- that the attachment system of the force-proving instrument allows axial application of the force when the instrument is used for tensile testing;
- that there is no interaction between the force transducer and its support on the calibration machine when the instrument is used for compression testing.

Clause B.2 gives an example of a method that can be used.

NOTE Other tests can be used, e.g. a test using a flat-based transducer with a spherical button or upper bearing surface.

7.1.4 Variable voltage test

This test is left to the discretion of the calibration service. For force-proving instruments requiring an electrical supply, verify that a variation of ±10 % of the line voltage has no significant effect. This verification can be carried out by means of a force transducer simulator or by another appropriate method.

7.2 Resolution of the indicator

7.2.1 Analogue scale

The thickness of the graduation marks on the scale shall be uniform and the width of the pointer shall be approximately equal to the width of a graduation mark.

The resolution, r, of the indicator shall be obtained from the ratio between the width of the pointer and the centre-to-centre distance between two adjacent scale graduation marks (scale interval), the recommended ratios being 1:2, 1:5 or 1:10, a spacing of 1,25 mm or greater being required for the estimation of a tenth of the division on the scale.

A vernier scale of dimensions appropriate to the analogue scale may be used to allow direct fractional reading of the instrument scale division.

7.2.2 Digital scale

The resolution is considered to be one increment of the last active number on the numerical indicator.

7.2.3 Variation of readings

If the readings fluctuate by more than the value previously calculated for the resolution (with no force applied to the instrument), the resolution shall be deemed to be equal to half the range of fluctuation.

7.2.4 Units

The resolution, r, shall be converted to units of force.

7.3 Minimum force

Taking into consideration the accuracy with which the deflection of the instrument can be read during calibration or during its subsequent use for verifying machines, the minimum force applied to a force-proving instrument shall comply with the two following conditions:

a) the minimum force shall be greater than or equal to:

   — $4\,000 \times r$ for class 00;

   — $2\,000 \times r$ for class 0,5;

   — $1\,000 \times r$ for class 1;

   — $500 \times r$ for class 2.

b) the minimum force shall be greater than or equal to 0,02 F_f.

7.4 Calibration procedure

7.4.1 Preloading

Before the calibration forces are applied, in a given mode (tension or compression), the maximum force shall be applied to the instrument three times. The duration of the application of each preload shall be between 60 s and 90 s.

7.4.2 Procedure

Carry out the calibration by applying two series of calibration forces to the force-proving instrument with increasing values only, without disturbing the device.

Then apply at least two further series of increasing and, if the force-proving instrument is to be calibrated in an incremental/decremental 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°). If this is not possible, it is permissible to adopt the following positions: 0°, 180° and 360° (see Figure 1).

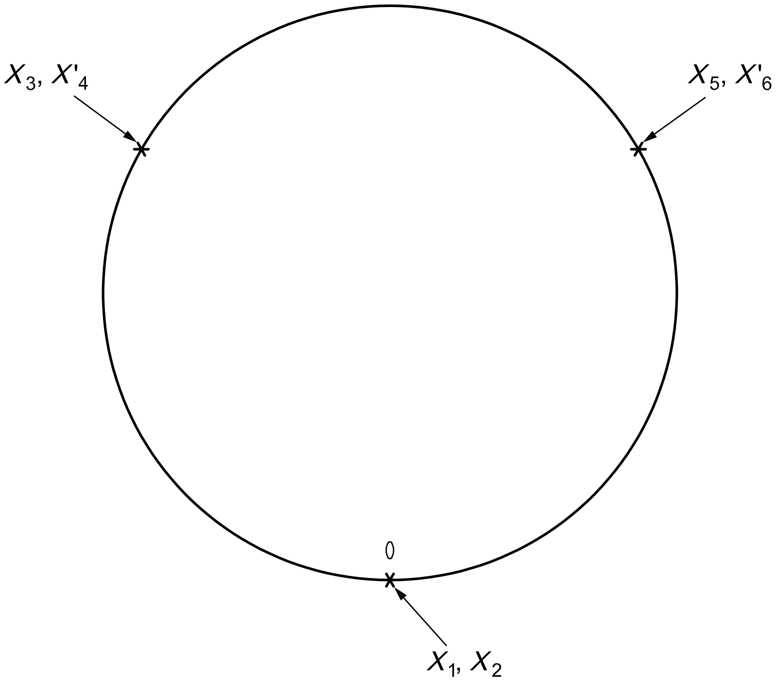


Figure 1 — Positions of the force-proving instrument

For the determination of the interpolation curve, the number of forces shall be not less than eight, and these forces shall be distributed as uniformly as possible over the calibration range. The interpolation curve shall be determined from the average values of the deflections with rotation, $\bar{X}_r$, as defined in 7.5.1.

If a periodic error is suspected, it is recommended that intervals between the forces which correspond to the periodicity of this error be avoided.

This procedure determines only a combined value of hysteresis of the device and of the calibration machine. Accurate determination of the hysteresis of the device may be performed on dead-weight machines. For other types of calibration machine, their hysteresis should be considered.

The force-proving instrument shall be preloaded three times to the maximum force in the direction in which the subsequent forces are to be applied. When the direction of loading is changed, the maximum force shall be applied three times in the new direction.

The readings corresponding to no force shall be noted after waiting at least 30 s after the force has been totally removed.

There should be a wait of at least 3 min between subsequent measurement series.

Instruments with detachable parts shall be dismantled, as for packaging and transport, at least once during calibration. In general, this dismantling shall be carried out between the second and third series of calibration forces. The maximum force shall be applied to the force-proving instrument at least three times before the next series of forces is applied.

Before starting the calibration of an electrical force-proving instrument, the zero signal may be noted (see Clause B.3).

7.4.3 Loading conditions

The time interval between two successive loadings shall be as uniform as possible, and no reading shall be taken within 30 s of the start of the force change. The calibration shall be performed at a temperature stable to within ±1 °C. This temperature shall be within the range 18 °C to 28 °C and shall be recorded. Sufficient time shall be allowed for the force-proving instrument to attain a stable temperature.

When it is known that the force-proving instrument is not temperature-compensated, care should be taken to ensure that temperature variations do not affect the calibration.

Strain gauge transducers shall be energized for at least 30 min before calibration.

7.4.4 Creep test

If the force-proving instrument is to be calibrated in an incremental-only loading direction, record its output at 30 s and 300 s after application or removal of the maximum calibration force, in each mode of force application, to enable its creep characteristics to be determined. If creep is measured at zero force, the maximum calibration force shall be maintained for at least 60 s prior to its removal. The creep test may be performed at any time after preloading during the calibration procedure.

The calibration certificate shall include the following information:

- the method of creep measurement (creep at maximum force or after force removal);
- when the creep measurement was performed (after preloading, after the last measurement series, etc.);
- the length of time for which the force was applied prior to removal (for creep determined at zero force).

7.4.5 Determination of deflection

A deflection is defined as the difference between a reading under force and a reading without force. This definition of deflection applies to output readings in electrical units as well as to output readings in length units.

7.5 Assessment of the force-proving instrument

7.5.1 Relative reproducibility and repeatability errors, b and b'

These errors are calculated for each calibration force and in both cases, i.e. with rotation of the force-proving instrument (b) and without rotation (b'), using the following equations:

$$b = \left| \frac{X_{\text{max}} - X_{\text{min}}}{\overline{X}_{\text{r}}} \right| \times 100 \qquad (1)$$

where $$\overline{X}_{\text{r}} = \frac{X_1 + X_3 + X_5}{3} \qquad (2)$$

and

$$b' = \left| \frac{X_2 - X_1}{\overline{X}_{\text{wr}}} \right| \times 100 \qquad (3)$$

where $$\overline{X}_{\text{wr}} = \frac{X_1 + X_2}{2} \qquad (4)$$

7.5.2 Relative interpolation error, f_{c}

This error is determined using a first-, second- or third-degree equation giving the deflection $\overline{X}_{\text{r}}$ as a function of the calibration force.

The equation used shall be indicated in the calibration report. The relative interpolation error shall be calculated from the equation:

$$f_{\text{c}} = \frac{\overline{X}_{\text{r}} - X_{\text{a}}}{X_{\text{a}}} \times 100 \qquad (5)$$

7.5.3 Relative zero error, f_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 error is calculated from the equation:

$$f_0 = \frac{i_{\text{f}} - i_{\text{o}}}{X_{\text{N}}} \times 100 \qquad (6)$$

The maximum relative zero error evaluated should be considered.

7.5.4 Relative reversibility error, v

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

The difference between the values obtained for both series with increasing forces and with decreasing forces enables the relative reversibility error to be calculated using the following equations:

$$v_1 = \left| \frac{X'_4 - X_3}{X_3} \right| \times 100 \qquad (7)$$

$$v_2 = \left| \frac{X'_6 - X_5}{X_5} \right| \times 100 \tag{8}$$

v is calculated as the mean value of v_1 and v_2:

$$v = \frac{v_1 + v_2}{2} \tag{9}$$

7.5.5 Relative creep error, c

Calculate the difference in outputs i_{30} obtained at 30 s and i_{300} obtained 300 s after the application or removal of the maximum calibration force and express this difference as a percentage of maximum deflection:

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

8 Classification of the force-proving instrument

8.1 Principle of classification

The range for which the force-proving instrument is classified is determined by considering each calibration force, one after the other, starting with the maximum force and decreasing to the lowest calibration force. The classification range ceases at the last force for which the classification requirements are satisfied.

The force-proving instrument can be classified either for specific forces or for interpolation, and for either incremental-only or incremental/decremental loading directions.

8.2 Classification criteria

8.2.1 The range of classification of a force-proving instrument shall at least cover the range 50 % to 100 % of F_N.

8.2.2 Case A: For instruments classified only for specific forces and incremental-only loading, the criteria which shall be considered are:

- the relative reproducibility, repeatability and zero errors;
- the relative creep error.

8.2.3 Case B: For instruments classified only for specific forces and incremental/decremental loading, the criteria which shall be considered are:

- the relative reproducibility, repeatability and zero errors;
- the relative reversibility error.

8.2.4 Case C: For instruments classified for interpolation and incremental-only loading, the criteria which shall be considered are:

- the relative reproducibility, repeatability and zero errors;
- the relative interpolation error;
- the relative creep error.

8.2.5 Case D: For instruments classified for interpolation and incremental/decremental loading, the criteria which shall be considered are:

- the relative reproducibility, repeatability and zero errors;
- the relative interpolation error;
- the relative reversibility error.

Table 2 gives the maximum allowable values of these parameters for each class of force-proving instrument and the uncertainty of the calibration forces.

Table 2 — Characteristics of force-proving instruments

Class	**Relative error of the force-proving instrument** %						**Expanded uncertainty of applied calibration force** (95 % level of confidence)
	of reproducibility	of repeatability	of interpolation	of zero	of reversibility	of creep	%
	b	b'	f_c	f_0	v	c	
00	0,05	0,025	±0,025	±0,012	0,07	0,025	±0,01
0,5	0,10	0,05	±0,05	±0,025	0,15	0,05	±0,02
1	0,20	0,10	±0,10	±0,050	0,30	0,10	±0,05
2	0,40	0,20	±0,20	±0,10	0,50	0,20	±0,10

8.3 Calibration certificate and duration of validity

8.3.1 If a force-proving instrument has satisfied the requirements of this International Standard at the time of calibration, the calibration authority shall draw up a certificate, in accordance with ISO/IEC 17025, stating at least the following information:

a) the identity of all elements of the force-proving instrument and loading fittings and of the calibration machine;

b) the mode of force application (tension/compression);

c) that the instrument is in accordance with the requirements of preliminary tests;

d) the class and the range (or forces) of validity and the loading direction (incremental-only or incremental/decremental);

e) the date and results of the calibration and, when required, the interpolation equation;

f) the temperature at which the calibration was performed;

g) the uncertainty of the calibration results (one method of determining the uncertainty is given in Annex C);

h) details of the creep measurement, if performed (see 7.4.4).

8.3.2 For the purposes of this International Standard, the maximum period of validity of the certificate shall not exceed 26 months.

A force-proving instrument shall be recalibrated when it sustains an overload higher than the test overload (see Clause B.1) or after repair.

9 Use of calibrated force-proving instruments

Force-proving instruments shall be loaded in accordance with the conditions under which they were calibrated. Precautions shall be taken to prevent the instrument from being subjected to forces greater than the maximum calibration force.

Instruments classified only for specific forces shall be used only for these forces.

Instruments classified for incremental-only loading shall be used only for increasing forces. Instruments classified for incremental/decremental loading may also be used to measure decreasing forces.

Instruments classified for interpolation may be used for any force in the interpolation range.

If a force-proving instrument is used at a temperature other than the calibration temperature, the deflection of the instrument shall, if necessary, be corrected for any temperature variation (see Clause B.4).

NOTE A change of zero of the unloaded force transducer indicates plastic deformation due to overloading of the force transducer. Permanent long-term drift indicates an influence of moisture on the strain gauge base or a bonding defect of the strain gauges.

Annex A
(informative)

Example of dimensions of force transducers and corresponding loading fittings

A.1 General

In order to calibrate force transducers in force standard machines and to enable easy axial installation in the materials testing machines to be verified, the following design specifications and dimensions may be considered.

A.2 Tensile force transducers

To aid assembly, it is recommended that the clamping heads on the face be machined down to the core diameter over a length of about two threads. See Table A.1.

The centring bores used in the manufacture of the force transducer should be retained.

Table A.1 — Dimensions of tensile force transducers for nominal forces of not less than 10 kN

Maximum (nominal) force of force-proving instrument[a]	**Maximum overall length**[b] mm	**Size of external thread of heads**[c]	**Minimum length of thread** mm	**Maximum width or diameter** mm
10 kN to 20 kN	500	M20 × 1,5[d]	16	110
40 kN and 60 kN	500	M20 × 1,5[d]	16	125
100 kN	500	M24 × 2	20	150
200 kN	500	M30 × 2	25	—
400 kN	600	M42 × 3	40	—
600 kN	650	M56 × 4	40	—
1 MN	750	M64 × 4	60	—
2 MN	950	M90 × 4	80	—
4 MN	1 300	M125 × 4	120	—
6 MN	1 500	M160 × 6	150	—
10 MN	1 700	M200 × 6	180	—
15 MN	2 000	M250 × 6	225	—
25 MN	2 500	M330 × 6	320	—

[a] Dimensions of tensile force transducers for nominal forces of less than 10 kN are not standardized.

[b] Length of tensile force transducer including any necessary thread adapters.

[c] Of the tensile force transducer or of the thread adapters.

[d] Pitch of 2 mm also permissible.

A.3 Compressive force transducers

To allow for the restricted mounting height in materials testing machines, compressive force transducers should not exceed the overall heights given in Table A.2.

The overall height includes the height of the associated loading fittings.

Table A.2 — Overall height of compressive force transducers

Maximum (nominal) force of force-proving instrument	**Maximum overall height[a] of devices for the verification of materials testing machines** mm	
	class 1[b]	class 2[b]
≤40 kN	145	115
60 kN	170	145
100 kN	220	145
200 kN	220	190
400 kN	290	205
600 kN	310	205
1 MN	310	205
2 MN	310	205
3 MN	330	205
4 MN	410	205
5 MN	450	350
6 MN	450	400
10 MN	550	400
15 MN	670	—

[a] The use of transducers having a greater overall height is permissible if the actual mounting clearances of the materials testing machine make this possible.

[b] In accordance with ISO 7500-1.

A.4 Loading fittings

A.4.1 General

Loading fittings should be designed in such a way that the line of force application is not distorted. As a rule, tensile force transducers should be fitted with two ball nuts, two ball cups and, if necessary, with two intermediate rings, while compressive force transducers should be fitted with one or two compression pads.

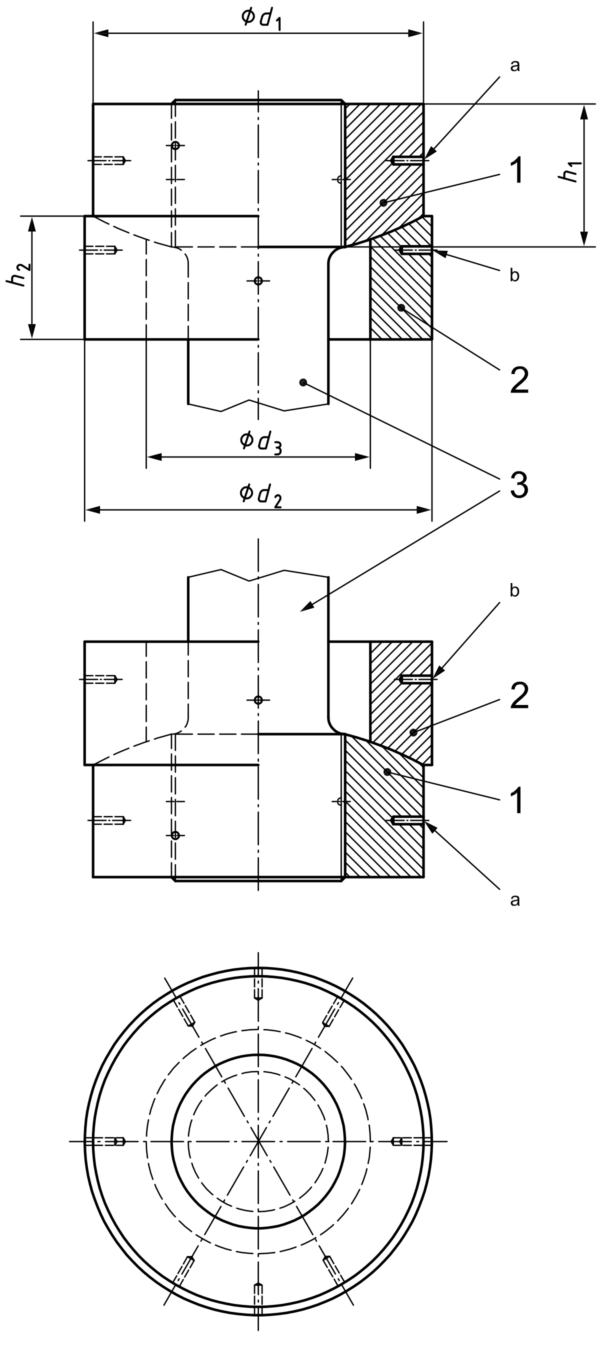
The dimensions recommended in A.4.2 to A.4.5 require the use of material with a yield strength of at least 350 N/mm^2.

A.4.2 Ball nuts and ball cups

Figure A.1 shows the shape of ball nuts and ball cups required for tensile force transducers. Their dimensions should be in accordance with Table A.3.

Large ball cups and ball nuts for maximum (nominal) forces of 4 MN and greater should be provided with blind holes distributed around the periphery as an aid to transportation and assembly. In the case of ball cups, two pairs of opposite bores are sufficient, one of which should be made in the centre plane and the other in the upper third of the top ball cup and in the lower third of the bottom ball cup (see Figure A.1).

In ball nuts, two opposite blind holes offset by 60° should be made in an upper plane, a mid plane and a lower plane.



Key

1 ball nut

2 ball cup

3 tensile force measuring rod

[a] Six bores.

[b] Four bores.

Figure A.1 — Ball nut, ball cup and tensile force measuring rod

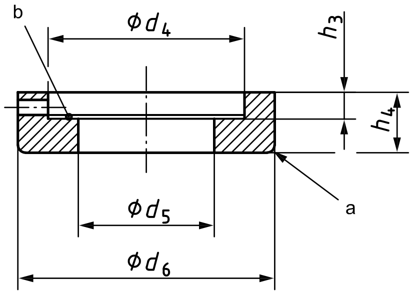
Table A.3 — Dimensions of ball nuts and ball cups for tensile force transducers with a maximum force of not less than 10 kN

Maximum (nominal) force of force-proving instrument	d_1 mm	d_2 (c11) mm	d_3 mm	h_1 mm	h_2 mm	r mm
From 10 kN to 40 kN	32	$35^{-0,120}_{-0,280}$	22	16	12	30
60 kN	43	$45^{-0,130}_{-0,290}$	27	18	15	30
100 kN	47	$50^{-0,130}_{-0,290}$	32	20	15	50
200 kN	60	$64^{-0,140}_{-0,330}$	44	25	15	50
400 kN and 600 kN	86	$90^{-0,170}_{-0,390}$	60	40	18	80
1 MN	115	$120^{-0,180}_{-0,400}$	74	60	25	100
2 MN	160	$165^{-0,230}_{-0,480}$	100	90	30	150
4 MN	225	$235^{-0,280}_{-0,570}$	150	120	40	250
6 MN	260	$270^{-0,300}_{-0,620}$	170	150	45	250
10 MN	335	$345^{-0,360}_{-0,720}$	220	180	55	300
15 MN	410	$420^{-0,440}_{-0,840}$	265	225	65	350
25 MN	550	$580^{-0,5}_{-1,5}$	345	310	85	500

A.4.3 Intermediate rings

Wherever necessary, type A or type B intermediate rings as shown in Figure A.2 or A.3, respectively, and specified in Table A.4 should be used for the verification of multi-range materials testing machines.

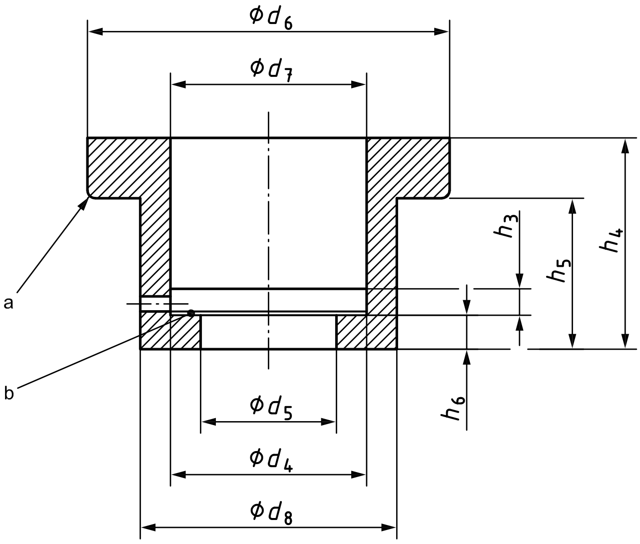
Intermediate rings should have a suitable holding fixture (e.g. threaded pins) for securing other mounting parts.



[a] Chamfer.

[b] Undercut (dimensions: 1,6 mm × 0,3 mm).

Figure A.2 — Type A intermediate ring



[a] Chamfer.

[b] Undercut (dimensions: 1,6 mm × 0,3 mm).

Figure A.3 — Type B intermediate ring

A.4.4 Adapters (extensions, reducer pieces, etc.)

If, owing to the design of the materials testing machine, adapters are required for mounting the force transducer, they should be designed so as to ensure central loading of the force transducer.

A.4.5 Loading pads

Loading pads are used as the force introduction components of compressive force transducers. If a loading pad has two flat surfaces for force transmission, they should be ground plane parallel.

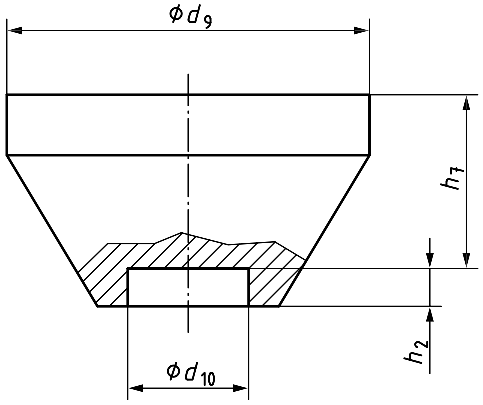
In the verification of force-proving instruments used in a force calibration machine or a force standard machine, the surface pressure on the compression platens of the machine should not be greater than 100 N/mm^2; if necessary, additional intermediate plates should be selected and installed (see Figure A.4) with a diameter, d_9, large enough to ensure that this condition is met.

Figure A.4 a) shows, by way of example, the shape of a loading pad for compressive force transducers having a convex area of force introduction; its height, h_7, should be equal to or greater than $d_9/2$.

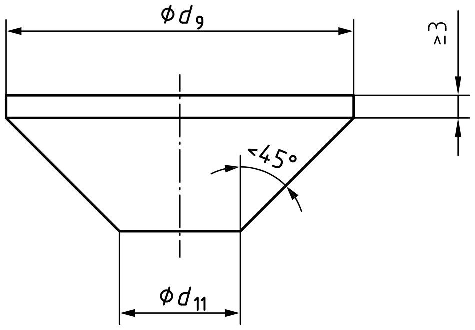
The height, h_8, and diameter, d_{10}, of all loading pads should, however, be adapted to the force introduction components in such a way that the loading pad can be located both centrally and without lateral contact to the force introduction component. The diameter, d_{10}, should therefore be 0,1 mm to 0,2 mm greater than the diameter of the force introduction component.

Figure A.4 b) shows, by way of example, the shape of a loading pad for compressive force transducers having a flat area of force introduction. The diameter, d_{11}, should be greater than or equal to the diameter of the force introduction component.

Dimensions in millimetres



a) Loading pad designed so as to reduce surface pressure for force transducers having a convex area of force introduction



b) Loading pad designed so as to reduce surface pressure for force transducers having a flat area of force introduction

Figure A.4 — Loading pads

Table A.4 — Dimensions of intermediate rings

Maximum (nominal) force of materials testing machine[a]	Maximum force of force-proving instrument	Type of intermediate ring	d_4 H7 mm	d_5 mm	d_6 c11 mm	d_7 mm	d_8 mm	h_3 mm	h_4 mm	h_5 mm	h_6 mm
60 kN	40 kN	A	$35^{+0,025}_{0}$	24	$45^{-0,130}_{-0,290}$	—	—	5	10	—	—
100 kN	40 kN	A	$35^{+0,025}_{0}$	24	$50^{-0,130}_{-0,290}$	—	—	7	15	—	—
	60 kN	A	$45^{+0,025}_{0}$	29		—	—	7	15	—	—
200 kN	40 kN	B	$35^{+0,025}_{0}$	24	$64^{-0,140}_{-0,330}$	36	46	5	34	22	12
	60 kN	A	$45^{+0,025}_{0}$	29		—	—	7	15	—	—
	100 kN	A	$50^{+0,025}_{0}$	34		—	—	7	15	—	—
400 kN and 600 kN	40 kN	B	$35^{+0,025}_{0}$	24	$90^{-0,170}_{-0,390}$	36	61	5	57	42	12
	60 kN	B	$45^{+0,025}_{0}$	29		46	61	7	57	42	12
	100 kN	B	$50^{+0,025}_{0}$	34		51	61	7	57	42	15
	200 kN	A	$64^{+0,030}_{0}$	47		—	—	12	20	—	—
1 MN	60 kN	B	$45^{+0,025}_{0}$	29	$120^{-0,180}_{-0,400}$	46	77	7	60	45	15
	100 kN	B	$50^{+0,025}_{0}$	34		51	77	7	60	45	15
	200 kN	B	$64^{+0,030}_{0}$	47		65	77	12	60	45	15
	400 kN and 600 kN	A	$90^{+0,035}_{0}$	65		—	—	18	32	—	—
2 MN	200 kN	B	$64^{+0,030}_{0}$	47	$165^{-0,230}_{-0,480}$	67	103	12	87	60	15
	400 kN and 600 kN	A	$90^{+0,035}_{0}$	65		—	—	18	48	—	—
	1 MN	A	$120^{+0,035}_{0}$	78		—	—	25	50	—	—
4 MN	400 kN and 600 kN	B	$90^{+0,035}_{0}$	65	$235^{-0,280}_{-0,570}$	92	158	18	130	95	35
	1 MN	B	$120^{+0,035}_{0}$	78		122	158	25	130	95	45
	2 MN	A	$165^{+0,040}_{0}$	105		—	—	27	62	—	—
6 MN	400 kN and 600 kN	B	$90^{+0,035}_{0}$	65	$270^{-0,300}_{-0,620}$	92	173	18	155	115	35
	1 MN	B	$120^{+0,035}_{0}$	78		122	173	25	155	115	45
	2 MN	A	$165^{+0,040}_{0}$	105		—	—	27	77	—	—
	4 MN	A	$235^{+0,046}_{0}$	160		—	—	35	60	—	—
10 MN	1 MN	B	$120^{+0,035}_{0}$	78	$345^{-0,360}_{-0,720}$	122	223	25	200	150	40
	2 MN	B	$165^{+0,040}_{0}$	105		167	223	27	200	150	60
	4 MN	A	$235^{+0,046}_{0}$	160		—	—	35	90	—	—
	6 MN	A	$270^{+0,052}_{0}$	185		—	—	40	75	—	—

[a] Tensile testing machines for nominal forces greater than 10 MN are special versions for which any necessary intermediate rings should be made by arrangement.

Annex B
(informative)

Additional information

B.1 Overloading test

The force-proving instrument is subjected, four times in succession, to an overload that should exceed the maximum force by a minimum of 8 % and a maximum of 12 %. Overloading is maintained for a period of 60 s to 90 s.

At least one overloading test should be done by the manufacturer before the instrument is released for calibration or service.

B.2 Example of a method of verifying that there is no interaction between the force transducer of an instrument used in compression and its support on the calibration machine

The force-proving instrument is loaded by means of intermediate bearing pads having a cylindrical shape and plane, convex and concave surfaces and which are in contact with the base of the device.

The concave and convex surfaces are considered as representing the limits of the absence of flatness and of variations in hardness of the bearing pads on which the instrument could be used when in operation.

The intermediate bearing pads are made of steel having a hardness between 400 HV 30 and 650 HV 30. The convexity and concavity of the surfaces are 1,0 ± 0,1 in 1 000 of the radius [(0,1 ± 0,01) % of the radius].

If a force-proving instrument is submitted for calibration with associated loading pads that will subsequently always be used with that force-proving instrument, the test device is considered to be a combination of the force-proving instrument plus the associated loading pads. This combination is loaded in turn through the plane and convex and concave bearing pads.

Two test forces are applied to the force-proving instrument, the first being the maximum force of the instrument and the second, the minimum calibration force for which deflection of the instrument is sufficient from the point of view of repeatability.

The tests are repeated in order to have three force applications for each of the three types of intermediate bearing pad. For each force, the difference between the mean deflection using concave and plane bearing pads and the difference between the mean deflection using convex and plane bearing pads should not exceed the limits given in Table B.1, in relation to the class of the force-proving instrument.

Table B.1 — Maximum permissible difference for the mean deflection

Class	**Maximum permissible difference,** %	
	at maximum force	at minimum force
00	0,05	0,1
0,5	0,1	0,2
1	0,2	0,4
2	0,4	0,8

If the force-proving instrument satisfies the requirements relating to the maximum force but does not fulfil that for the minimum force, the smallest force for which the instrument fulfils the condition is determined.

The smallest increase in the force used to determine the smallest force satisfying the condition is left to the discretion of the authority qualified to carry out the calibration.

Generally, there is no need to repeat these tests with intermediate bearing pads each time the instrument is calibrated, but only after an overhaul of the force-proving instrument.

B.3 Comments on the record of the zero signal of the unloaded force transducer

A change of the zero of the unloaded force transducer indicates plastic deformation due to overloading of the force transducer. Permanent long-term drift indicates an influence of moisture on the strain gauge base or a bonding defect of the strain gauges.

B.4 Temperature corrections of calibrated force-proving instruments

The correction of the deflection of the instrument for any temperature variation is calculated according to the following equation:

$$D_\mathrm{t} = D_\mathrm{e} \left[1 + K(t - t_\mathrm{e})\right] \tag{B.1}$$

where

D_t is the deflection at the temperature t;

D_e is the deflection at the calibration temperature, t_e;

K is the temperature coefficient of the instrument, in °C^{-1}.

For instruments other than those having a force transducer with electrical outputs made of steel containing not more than 7 % of alloying elements, the value $K = 0{,}000\,27$ °C^{-1} may be used.

For instruments made of material other than steel or which include force transducers with electrical outputs, the value of K should be determined experimentally and should be provided by the manufacturer. The value used will need to be stated on the calibration certificate of the instrument.

Table B.2 gives the deflection corrections for instruments of the first type. These corrections were obtained with $K = 0{,}000\,27$ °C^{-1}.

NOTE When the instrument is made of steel and the deflection is measured in units of length, the temperature correction is equal to approximately 0,001 for each variation of 4 °C.

Most force transducers with electrical outputs are thermally compensated in the range of application (see the second paragraph in 7.4.3). In these cases, a temperature correction might not be necessary.

Generally, it is sufficient to measure the temperature of the device to the nearest 1 °C.

If a deflection has been measured with a force-proving instrument at a temperature greater than the calibration temperature and it is desired to obtain the deflection of the instrument for the calibration temperature, the deflection correction given in Table B.2 is deducted from the deflection measured.

When the measurement is carried out with a force-proving instrument at a temperature lower than the calibration temperature, the correction is added.

EXAMPLE

- temperature of the force-proving instrument: 22 °C;
- deflection observed: 729,6 divisions;
- calibration temperature: 20 °C;
- temperature variation: 22 °C – 20 °C = +2 °C.

In the column corresponding to the variation of +2 °C, the nearest deflection that exceeds 729,6 divisions is 833 divisions. For this value of the deflection, Table B.2 gives a correction of 0,4 divisions.

The corrected deflection is therefore 729,6 – 0,4 = 729,2 divisions.

Table B.2 — Deflection corrections for temperature variations of a steel force-proving instrument not having a force transducer with electrical outputs

Deflection corrections scale divisions	**Maximum deflection to which correction is applied for temperature variations in relation to the calibration temperature** scale divisions							
	1 °C	2 °C	3 °C	4 °C	5 °C	6 °C	7 °C	8 °C
0,0	185	92	61	46	37	30	26	23
0,1	555	277	185	138	111	92	79	69
0,2	925	462	308	231	185	154	132	115
0,3	1 296	648	432	324	259	216	185	162
0,4	1 666	833	555	416	333	277	238	208
0,5	2 037	1 018	679	509	407	339	291	254
0,6		1 203	802	601	481	401	343	300
0,7		1 388	925	694	555	462	396	347
0,8		1 574	1 049	787	629	524	449	393
0,9		1 759	1 172	879	703	586	502	439
1,0		1 944	1 296	972	777	648	555	486
1,1		2 129	1 419	1 064	851	709	608	532
1,2			1 543	1 157	925	771	661	578
1,3			1 666	1 250	999	833	714	625
1,4			1 790	1 342	1 074	895	767	671
1,5			1 913	1 435	1 148	956	820	717
1,6			2 037	1 527	1 222	1 018	873	763
1,7			2 160	1 620	1 296	1 080	925	810
1,8				1 712	1 370	1 141	978	856
1,9				1 805	1 444	1 203	1 031	902
2,0				1 898	1 518	1 265	1 084	949
2,1				1 990	1 592	1 327	1 137	995
2,2				2 083	1 666	1 388	1 190	1 041
2,3					1 740	1 450	1 243	1 087
2,4					1 814	1 512	1 296	1 134
2,5					1 888	1 574	1 349	1 180

Annex C
(informative)

Measurement uncertainty of the calibration and subsequent use of the force-proving instrument

C.1 Uncertainty of the calibration results for the force-proving instrument

C.1.1 General

For instruments classified for interpolation, the calibration uncertainty is the uncertainty in the force value calculated from the interpolation equation, at any deflection, for increasing forces only. For instruments classified for specific forces only, the calibration uncertainty is the uncertainty in the force corresponding to any deflection equal to one of the mean deflections obtained during the calibration, for increasing forces only.

At each calibration force, F, a combined standard uncertainty, u_c, expressed in units of force, is calculated from the readings obtained during the calibration. These combined standard uncertainties are plotted against force, and a least-squares fit covering all the values is calculated. The coefficients of this fit are then multiplied by the coverage factor $k = 2$ to give an expanded uncertainty value, U, for any force within the calibration range. An expanded relative uncertainty value, W, can also then be calculated.

$$u_\mathrm{c} = \sqrt{\sum_{i=1}^{8} u_i^2} \tag{C.1}$$

and

$$U = k \times u_\mathrm{c} \tag{C.2}$$

and

$$W = U/F \tag{C.3}$$

where

u_1 is the standard uncertainty associated with the applied calibration force;

u_2 is the standard uncertainty associated with the reproducibility of the calibration results;

u_3 is the standard uncertainty associated with the repeatability of the calibration results;

u_4 is the standard uncertainty associated with the resolution of the indicator;

u_5 is the standard uncertainty associated with the creep of the instrument;

u_6 is the standard uncertainty associated with the drift in zero output;

u_7 is the standard uncertainty associated with temperature of instrument;

u_8 is the standard uncertainty associated with interpolation.

The expanded relative uncertainty, W, may also be calculated from a combination of relative standard uncertainties, w_i:

$$w_\mathrm{c} = \sqrt{\sum_{i=1}^{8} w_i^2} \tag{C.4}$$

and

$$W = k \times w_\mathrm{c} \tag{C.5}$$

and

$$U = W \times F \tag{C.6}$$

where

w_1 is the relative standard uncertainty associated with applied calibration force;

w_2 is the relative standard uncertainty associated with reproducibility of calibration results;

w_3 is the relative standard uncertainty associated with repeatability of calibration results;

w_4 is the relative standard uncertainty associated with resolution of indicator;

w_5 is the relative standard uncertainty associated with creep of instrument;

w_6 is the relative standard uncertainty associated with the drift in the zero output;

w_7 is the relative standard uncertainty associated with the temperature of the instrument;

w_8 is the relative standard uncertainty associated with interpolation.

NOTE 1 The interpolation component (u_8, w_8) is not taken into account in the calibration uncertainty with instruments classified for specific forces only.

NOTE 2 The relative uncertainty can be expressed as a percentage by multiplying by 100.

C.1.2 Calculation of calibration force uncertainty, u_1, w_1

u_1 is simply the standard uncertainty associated with the forces applied by the calibration machine, expressed in units of force, and w_1 is the same expressed as a relative value.

C.1.3 Calculation of reproducibility uncertainty, u_2, w_2

u_2 is the standard deviation associated with the mean incremental deflections obtained during the calibration, expressed in units of force, and w_2 is the same expressed as a relative value.

$$u_2 = \left| \frac{F_\mathrm{N}}{X_\mathrm{N}} \right| \times \sqrt{\frac{1}{6} \times \sum_{i=1,3,5} \left(X_i - \bar{X}_\mathrm{r} \right)^2} \tag{C.7}$$

and

$$w_2 = \frac{1}{\left|\bar{X}_\mathrm{r}\right|} \times \sqrt{\frac{1}{6} \times \sum_{i=1,3,5} \left(X_i - \bar{X}_\mathrm{r}\right)^2} \tag{C.8}$$

where X_i is the deflection obtained in the incremental series 1, 3, and 5.

NOTE This is not the reproducibility of a measured force during the force-proving instrument's subsequent use.

C.1.4 Calculation of repeatability uncertainty, u_3, w_3

u_3 is the uncertainty contribution due to the repeatability of the measured deflection, expressed in units of force, and w_3 is the same expressed as a relative value. It can be assumed that, at each force, F:

$$u_3 = \frac{b' \times F}{100 \times \sqrt{3}} \tag{C.9}$$

and

$$w_3 = \frac{b'}{100 \times \sqrt{3}} \tag{C.10}$$

where b' is the relative repeatability error as defined in 7.5.1.

C.1.5 Calculation of resolution uncertainty, u_4, w_4

Each deflection value is calculated from two readings (the reading with an applied force minus the reading at zero force). Because of this, the resolution of the indicator needs 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 units of force:

$$u_4 = \frac{r}{\sqrt{6}} \tag{C.11}$$

and

$$w_4 = \frac{1}{\sqrt{6}} \times \frac{r}{F} \tag{C.12}$$

C.1.6 Calculation of creep uncertainty, u_5, w_5

This uncertainty component is due to the fact that, at a given force, the measured deflection can be influenced by the previous short-term loading history. One measure of this influence is the change in transducer output in the period from 30 s to 300 s after application or removal of the maximum calibration force. This effect is not included in the reproducibility because, generally, the same calibration machine is used for all measurement series and the time/loading profile will be the same.

This effect can be estimated as follows:

$$u_5 = \frac{c \times F}{100 \times \sqrt{3}} \tag{C.13}$$

and

$$w_5 = \frac{c}{100 \times \sqrt{3}} \tag{C.14}$$

If the creep test is not performed, the creep uncertainty can be estimated by dividing the hysteresis by a factor of 3. Therefore, the following equation can be used to calculate this uncertainty contribution for increasing forces:

$$u_5 = \frac{\nu \times F}{100 \times 3\sqrt{3}} \tag{C.15}$$

and

$$w_5 = \frac{\nu}{100 \times 3\sqrt{3}} \tag{C.16}$$

C.1.7 Calculation of zero drift uncertainty, u_6, w_6

This uncertainty component is due to the fact that the 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 effect 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, f_0, so this effect can be estimated as follows:

$$u_6 = \frac{f_0 \times F}{100} \tag{C.17}$$

and

$$w_6 = \frac{f_0}{100} \tag{C.18}$$

C.1.8 Calculation of temperature uncertainty, u_7, w_7

This uncertainty is the contribution due to the variation of temperature throughout the calibration, together with the uncertainty in the measurement of the calibration temperature. The sensitivity of the instrument to temperature needs to be estimated, either by tests or from the manufacturer's specifications or by theory or by experience. Expressing this component in units of force or as a relative value, we have:

$$u_7 = K \times \frac{\Delta T}{2} \times \frac{1}{\sqrt{3}} \times F \tag{C.19}$$

and

$$w_7 = K \times \frac{\Delta T}{2} \times \frac{1}{\sqrt{3}} \tag{C.20}$$

where

K is the instrument's temperature coefficient, in reciprocal degrees Celsius (°C^{-1});

ΔT is the calibration temperature range, allowing for the uncertainty in the measurement of the temperature.

C.1.9 Calculation of interpolation uncertainty, u_8, w_8

C.1.9.1 General

This component is not taken into account in the calibration uncertainty for instruments classified for specific forces only.

It is the contribution due to the plotted force/deflection points not all falling on the best-fit line, leading to an uncertainty in the interpolation equation. Either of the two methods given in C.1.9.2 and C.1.9.3 may be used to calculate this contribution.

C.1.9.2 Residual method

The component can be estimated using statistical theory. Assuming that the calibration forces are evenly distributed, it can be simplified to the following equations:

$$u_8 = \frac{F_N}{X_N}\sqrt{\frac{\delta_r}{n-d-1}} \tag{C.21}$$

and

$$w_8 = \frac{F_N}{F \times X_N}\sqrt{\frac{\delta_r}{n-d-1}} \tag{C.22}$$

where

δ_r is the sum of the squared deviations between the mean deflection and the value calculated from the interpolation equation;

n is the number of force calibration steps;

d is the degree of the interpolation equation.

C.1.9.3 Deviation method

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

$$u_8 = \left|\frac{\bar{X}_r - X_a}{\bar{X}_r}\right| \times F \tag{C.23}$$

or

$$w_8 = \left|\frac{\bar{X}_r - X_a}{\bar{X}_r}\right| \tag{C.24}$$

C.1.10 Calculation of combined calibration standard uncertainty and of expanded uncertainty

C.1.10.1 General

The calculation of the combined standard uncertainty and expanded uncertainty is carried out either in force units (for u_c and U) or as relative values (for w_c and W), as shown in C.1.10.2 and C.1.10.3, respectively.

C.1.10.2 Combined standard uncertainty and expanded uncertainty in force units

For each calibration force, calculate the combined standard uncertainty, u_c, by combining the individual standard uncertainties in quadrature:

$$u_\mathrm{c} = \sqrt{\sum_{i=1}^{8} u_i^2} \tag{C.25}$$

NOTE This equation is the same as Equation (C.1).

Plot a graph of u_c against force and then determine the coefficients of the best-fit least-squares line through all of the data points.

The form of the fitted line (e.g. linear, polynomial, exponential) will depend on the calibration results. A linear equation is preferred for reasons of simplicity. If this results in values lower than the minimum combined uncertainty value, a more conservative fit should be employed and/or a minimum value for the uncertainty should be specified. It is suggested that this be equal to the minimum combined standard uncertainty obtained (in units of force).

The expanded uncertainty, U, is given by the equation whose coefficients are twice those of the best-fit equation. For any force within the calibration range, an expanded uncertainty can then be calculated, expressed in force units.

C.1.10.3 Combined standard uncertainty and expanded uncertainty as relative values

For each calibration force, calculate the combined standard uncertainty, w_c, by combining the individual standard uncertainties in quadrature:

$$w_\mathrm{c} = \sqrt{\sum_{i=1}^{8} w_i^2} \tag{C.26}$$

NOTE This equation is the same as Equation (C.4).

Plot a graph of w_c against force and then determine the coefficients of the best-fit least-squares line through all of the data points.

The form of the fitted line (e.g. linear, polynomial, exponential) will depend on the calibration results. If this results in values lower than the minimum combined uncertainty value, a more conservative fit should be employed and/or a minimum value for the uncertainty should be specified for the relevant parts of the calibration range. It is suggested that this be equal to the minimum combined standard uncertainty obtained.

The expanded uncertainty, W, is given by the equation whose coefficients are twice those of the best-fit equation. For any force within the calibration range, an expanded uncertainty can then be calculated, expressed as a relative value.

C.2 Uncertainty during the force-proving instrument's subsequent use

C.2.1 General

The uncertainty associated with the force calculated from the deflection obtained from the force-proving instrument subsequent to its calibration will include contributions from a number of sources:

a) calibration uncertainty;

b) resolution;

c) contribution due to reversibility;

d) drift in sensitivity since calibration;

e) effect of being used at a different temperature;

f) effect of being used with different end-loading conditions;

g) effect of being used with different parasitic components;

h) effect of being used with a different time/loading profile;

i) effect of linear approximations to interpolation equation;

j) if applicable, effect of a replacement indicator.

It can be assumed that none of these effects is correlated, so their standard uncertainties can be summed in quadrature to calculate a combined standard uncertainty at each force (assuming that any known errors have been corrected for). For example, if the temperature sensitivity of the transducer is known, and so is the temperature difference (between calibration and subsequent use), either a correction should be made to the calculated force or the effect should be added to the uncertainty linearly, rather than in quadrature.

C.2.2 Calibration uncertainty

The calibration uncertainty is half the value of the expanded uncertainty calculated in C.1.10 using the expanded uncertainty equation.

C.2.3 Resolution uncertainty

The measured force comes from new deflection values. Because of this, the resolution of the indicator needs to be included again in a way similar to that described in C.1.5. If the readings fluctuate by more than the resolution of the indicator, the resolution should be taken as half the range of fluctuation.

C.2.4 Calculation of contribution due to reversibility

The reversibility error, v, defined in 7.5.4 is not a component of the calibration uncertainty. The way to take this characteristic into account will depend on how the transducer is to be used after the calibration.

If the user makes only increasing measurements, no component due to reversibility should be included in the uncertainty of the measured force.

However, if the user makes measurements with decreasing values of force and without any correction, the uncertainty of the measured force will need to take into account the reversibility, v, by adding an additional component:

$$u_{\mathrm{rev}} = \frac{v \times F}{100 \times \sqrt{3}} \tag{C.27}$$

and

$$w_{\mathrm{rev}} = \frac{v}{100 \times \sqrt{3}} \tag{C.28}$$

This component could be stated in the calibration certificate. It could also be added in quadrature to the calibration uncertainty components described in Clause C.1 to obtain a combined calibration uncertainty including an additional reversibility effect.

C.2.5 Drift

This component may be estimated from the history of the results obtained from the transducer in previous calibrations. The exact uncertainty distribution (and possibly even an estimated error correction) will depend on the individual transducer, but a rectangular distribution with an expanded uncertainty of ± the largest previous change is suggested as a conservative estimate. If such information is not available, an estimate should be made based on the performance history of similar devices.

C.2.6 Temperature effect

The temperature effect on zero output can be ignored, as the calculation of deflection makes it insignificant, but the effect of temperature on sensitivity needs to be allowed for. If the actual temperature sensitivity of the force-proving instrument is known, a correction should be made to the calculated force. If, as is more likely to be the case, the only information is the manufacturer's specification tolerance, an uncertainty component based on this figure and the difference in temperature between the force-proving instrument's calibration and its subsequent use should be employed. It is recommended that a rectangular distribution be used. However, the coefficient (or the tolerance) is usually given for a stabilized temperature with no gradient. If the transducer is used in conditions in which it is subject to temperature gradients, an additional uncertainty contribution should be taken into account.

C.2.7 End-loading effect

The bearing-pad test described in Clause B.2 gives an indication of the sensitivity of a compression force transducer to end-loading effects. The results of such tests, together with information as to the conditions in which a transducer will subsequently be used, should enable realistic uncertainty contributions for these effects to be determined.

C.2.8 Effect of parasitic components

The reproducibility included in the calibration uncertainty is only valid for a mean of three measurements made on the calibration machine. Usually, parasitic components are encountered during the force-proving instrument's subsequent use which are larger than the parasitic components encountered during calibration.

Therefore, it is recommended that the user repeat the force measurement, rotating the transducer around the force axis between series of measurements. A component related to the observed variation can then be taken into account.

If it is not possible to repeat measurements with rotation, the range of the parasitic component should be estimated and the sensitivity of the transducer to parasitic components evaluated. An uncertainty component based on the product of the range and the sensitivity should then be included.

C.2.9 Time/loading profile

The force-proving instrument calibration method (as defined in this International Standard) and its subsequent use to verify a uniaxial testing machine (as defined in ISO 7500-1) specify different time/loading profiles (a wait of 30 s before taking a reading is specified in this International Standard, whereas ISO 7500-1 allows calibration with a slowly increasing force). If the force-proving instrument is sensitive to time/loading effects, these different protocols would lead to errors in the calculated force. The creep and zero drift uncertainty contributions to the calibration uncertainty will cover these effects to some degree, but an additional uncertainty contribution might be needed, depending on the application.

Care should be taken if no preload can be applied before the use of the force-proving instrument, particularly if it is to be used in both loading modes (i.e. from tension to compression or *vice versa*).

C.2.10 Effect of approximations to the calibration equation

If the calibration equation given in the certificate is not used, a component should be added based on the differences between the calibration equation and the equation which is used.

Some indicators allow points from the calibration curve to be input, so that the display is in units of force, but carry out linear interpolation between these points, rather than use the calibration equation. If this is the case, the effect of this approximation to the curve should be investigated and, if significant, an uncertainty contribution should be included.

C.2.11 Effect of a replacement indicator

The deviation between the two indicators should be determined (there are several methods, e.g. calibration of both indicators, use of a common bridge simulator) and the uncertainty of this deviation should be estimated (including factors such as the calibration uncertainty of the indicators and the stability of the common bridge simulator).

If corrections are made, the uncertainty of the deviation should be taken into account. If no corrections are made, the deviation and its uncertainty should be considered.

C.2.12 Effect of dynamic force

This International Standard concerns only static force measurement. If the force-proving instrument is used under dynamic conditions, additional contributions should be taken into account. For example, the frequency responses of the force transducer and indicator, and the interaction with the mechanical structure, can strongly influence the measurement results. This requires a detailed analysis of dynamic measurement, which is not part of this International Standard.

Bibliography

[1] ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

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