BS EN ISO 7500-1:2015

BSI Standards Publication

Metallic materials — Calibration and verification of static uniaxial testing machines

Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system

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National foreword

This British Standard is the UK implementation of EN ISO 7500-1:2015. It supersedes BS EN ISO 7500-1:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/101/1, Uniaxial testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

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European foreword

This document (EN ISO 7500-1:2015) has been prepared by Technical Committee ISO/TC 164 "Mechanical testing of metals" in collaboration with Technical Committee ECISS/TC 101 “Test methods for steel (other than chemical analysis)” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2016, and conflicting national standards shall be withdrawn at the latest by June 2016.

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

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Endorsement notice

The text of ISO 7500-1:2015 has been approved by CEN as EN ISO 7500-1:2015 without any modification.

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

This fourth edition cancels and replaces the third edition (ISO 7500-1:2004) which has been technically revised.

ISO 7500 consists of the following parts, under the general title *Metallic materials — Calibration and verification of static uniaxial testing machines*:

— *Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

— *Part 2: Tension creep testing machines — Verification of the applied force*

Metallic materials — Calibration and verification of static uniaxial testing machines —

Part 1:
Tension/compression testing machines — Calibration and verification of the force-measuring system

1 Scope

This part of ISO 7500 specifies the calibration and verification of tension/compression testing machines.

The verification consists of:

— a general inspection of the testing machine, including its accessories for the force application;

— a calibration of the force-measuring system of the testing machine;

— a confirmation that the performance properties of the testing machine achieve the limits given for a specified class.

NOTE This part of ISO 7500 addresses the static calibration and verification of the force-measuring systems. The calibration values are not necessarily valid for high-speed or dynamic testing applications. Further information regarding dynamic effects is given in the Bibliography.

CAUTION — Some of the tests specified in this part of ISO 7500 involve the use of processes which could lead to a hazardous situation.

2 Normative references

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

ISO 376, *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*

3 Terms and definitions

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

3.1
calibration
operation that establishes the relationship between the force values (with associated uncertainties) indicated by the testing machine and those measured by one or more force-proving instruments

3.2
verification
confirmation, based on analysis of measurements in accordance with this standard, that the performance properties of the testing machine achieve the limits given for a specified class

4 Symbols and their meanings

Symbols and their meanings are given in Table 1.

Table 1 — Symbols and their meanings

Symbol	Unit	Meaning
a	%	Relative resolution of the force indicator of the testing machine
a_F	%	Relative resolution of the force indicator of the testing machine at the applied force
a_Z	%	Relative resolution of the force indicator of the testing machine at zero force
b	%	Relative repeatability error of the force-measuring system of the testing machine
b_{al}	%	Allowable value of b for a given class
ΔF	N	Relative error of the force
Δm	kg	Relative error of the mass
Δg	m/s^2	Relative error of the acceleration due to gravity
E	%	Estimated mean relative error
E'	%	Estimated mean relative reversibility error
f_0	%	Relative zero error of the force-measuring system of the testing machine
F	N	Reference force indicated by the force-proving instrument with increasing test force
F'	N	Reference force indicated by the force-proving instrument with decreasing test force
F_c	N	Reference force indicated by the force-proving instrument with increasing test force, for the complementary series of measurements for the smallest range used
F_i	N	Force indicated by the force indicator of the testing machine to be verified, with increasing test force
F_i'	N	Force indicated by the force indicator of the testing machine to be verified, with decreasing test force
$\bar{F}_i$, $\bar{F}$	N	Arithmetic mean of several measurements of F_i and F for the same discrete force
F_{ic}	N	Force reading on the force indicator of the testing machine to be verified, with increasing test force, for the complementary series of measurements for the smallest range used
F_{i0}	N	Residual indication of the force indicator of the testing machine to be verified after removal of force
F_N	N	Maximum value of the calibrated range of the force indicator of the testing machine
g	m/s^2	Local acceleration due to gravity
k		Coverage factor used to calculate the expanded uncertainty from the combined uncertainty
m	kg	Mass of dead weights used to generate a calibration force
q	%	Mean relative indication error of the force-measuring system of the testing machine
q_i	%	The i^{th} measurement of the relative indication error of the force-measuring system of the testing machine
q_{al}	%	Allowable value of q for a given class
q_{max}	%	The maximum value of q at each calibration point
q_{min}	%	The minimum value of q at each calibration point
q_{T1}	%	Relative indication error determined at a crossover point using force-proving instrument 1

Table 1 *(continued)*

Symbol	Unit	Meaning
q_{T2}	%	Relative indication error determined at a crossover point using force-proving instrument 2
r	N	Resolution of the force indicator of the testing machine
u_c	%	Combined uncertainty
u_i	%	Uncertainty component
u_{rep}	%	Uncertainty component due to repeatability
u_{res}	%	Uncertainty component due to resolution
u_{std}	%	Uncertainty component due to the calibration standard used
U	%	Expanded uncertainty
U'	%	Expanded reversibility uncertainty
U_{T1}	%	Expanded uncertainty using force-proving instrument 1 at a crossover point
U_{T2}	%	Expanded uncertainty using force-proving instrument 2 at a crossover point
v	%	Relative reversibility error of the force-measuring system of the testing machine
ρ_{air}	kg/m^3	Density of air
ρ_m	kg/m^3	Density of the dead weights

5 General inspection of the testing machine

The calibration of the testing machine shall only be carried out if the machine is in good working order. For this purpose, a general inspection of the machine shall be carried out before calibration of the force-measuring system of the machine (see Annex A).

NOTE Good metrological practice requires a calibration run prior to any maintenance or adjustments to the testing machine to determine the “as found” condition of the machine.

Information on the inspection of the loading platens is provided in Annex B. Uncertainty of the calibration results is discussed in Annex C.

6 Calibration of the force-measuring system of the testing machine

6.1 General

This calibration shall be carried out for each of the force ranges used and with all force indicators in use. Any accessory devices (e.g. pointer, recorder) that may affect the force-measuring system shall, where used, be verified in accordance with 6.4.6.

If the testing machine has several force-measuring systems, each system shall be regarded as a separate testing machine. The same procedure shall be followed for double-piston hydraulic machines.

The calibration shall be carried out using force-proving instruments with the following exception; if the force to be verified is below the lower limit of the smallest capacity force-proving device used in the calibration procedure, use known masses.

When more than one force-proving instrument is required to calibrate a force range, the maximum force applied to the smaller device shall be the same as the minimum force applied to the next force-proving instrument of higher capacity. When a set of known masses is used to verify forces, the set shall be considered as a single force-proving instrument.

The calibration may be carried out with constant indicated forces, F_i or the calibration can be carried out with constant reference forces, F. Calibration can be carried out using a slowly increasing force for increasing force levels or a slowly decreasing force for decreasing force levels.

NOTE The word “constant” signifies that the same nominal value of F_i (or F) is used for the three series of measurements (see 6.4.5).

The instruments used for the calibration shall have a certified traceability to the international system of units.

The force-proving instrument shall comply with the requirements specified in ISO 376. The class of the instrument shall be equal to or better than the class for which the testing machine is to be calibrated. In the case of dead weights, the relative error of the force generated by these weights shall be within ± 0,1 %.

The exact equation giving the force, F, in newtons, created by the dead weight of mass m, in kilograms, is:

$$F = mg\left[1 - \frac{\rho_{\mathrm{air}}}{\rho_m}\right] \tag{1}$$

This force can be calculated using the following approximate formula:

$$F = mg \tag{2}$$

The relative error of the force can be calculated from the relative errors of mass and acceleration due to gravity, using the formula:

$$\frac{\Delta F}{F} = \frac{\Delta m}{m} + \frac{\Delta g}{g} \tag{3}$$

6.2 Determination of the resolution

6.2.1 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), multiplied by the value of force which one scale interval represents. The recommended ratios are 1:2, 1:5 or 1:10, a spacing of 2,5 mm or greater being required for the determination of one-tenth of a scale division.

6.2.2 Digital scale

The resolution is taken to be one increment of the count of the numerical indicator.

6.2.3 Variation of readings

If the readings vary by more than the value previously calculated for the resolution (with the force-proving instrument unloaded and with the motor and/or drive mechanism and control on for determining the sum of all electrical noise), the resolution, r, shall be deemed to be equal to half the range of fluctuation plus one increment.

NOTE 1 This only determines the resolution due to system noise and does not account for control errors, e.g. in the case of hydraulic machines.

NOTE 2 For auto-ranging machines, the resolution of the indicator changes as the resolution or gain of the system changes.

6.2.4 Unit

The resolution, r, shall be expressed in units of force.

6.3 Prior determination of the relative resolution of the force indicator

The relative resolution, a, of the force indicator is defined by the relationship:

$$a = \frac{r}{F_\mathrm{i}} \times 100 \qquad (4)$$

where

r is the resolution defined in 6.2;

F_i is the force indicated by the force indicator of the testing machine.

The relative resolution shall be determined at each calibration point and shall not exceed the values given in Table 2 for the class of machine being verified.

6.4 Calibration procedure

6.4.1 Alignment of the force-proving instrument

Mount tension force-proving instruments in the machine in such a way as to minimize any effects of bending (see ISO 376). For the alignment of a force-proving instrument in the compression mode, mount a platen with a ball nut on the instrument if the machine does not have an incorporated ball cup.

For calibration of tension and compression modes on testing systems that do not use compression platens for testing, the force proving device may be attached to the testing machine with threaded studs. In this case, the force proving instrument shall have been calibrated in a similar fashion (i.e. with threaded studs) and rotation of the force-proving instrument through an angle of 120° is required between each series of measurements during the calibration of the testing machine.

If the machine has two work areas with a common force application and indicating device, one calibration could be performed, so that e.g. compression in the upper work area equals tension in the lower work area, and vice versa. The certificate should carry an appropriate comment.

6.4.2 Temperature compensation

The calibration shall be carried out at an ambient temperature of between 10 °C and 35 °C. The temperature at which the calibration is carried out shall be noted in the verification report.

A sufficient period of time shall be provided to allow the force-proving instrument to reach a stable temperature. The temperature of the force-proving instrument shall not change by more than 2 °C from the beginning to the end of each calibration run. If necessary, temperature corrections shall be applied to the readings (see ISO 376).

6.4.3 Conditioning of the testing machine and force-proving instrument

Immediately prior to the calibration procedure, the force-proving instrument, in position in the machine, shall be preloaded at least three times between zero and the maximum force to be measured.

6.4.4 Procedure

Use either or a combination of the following methods:

a) a nominal force, F_i, indicated by the force indicator of the machine is applied by the machine and the reference force, F, indicated by the force-proving instrument is noted.

b) a nominal reference force, F, indicated by the force-proving instrument is applied by the machine and the force, F_i, indicated by the force indicator of the machine is noted.

The word nominal implies that it is not necessary to repeat the exact values of force in each series of measurements, however they should be approximately the same.

6.4.5 Application of discrete forces

Three series of measurements shall be taken with increasing force. For machines applying not more than five discrete levels of force, each value of relative error shall not exceed the values given in Table 2 for a specific class. For machines applying more than five discrete levels of force, each series of measurements shall comprise at least five discrete force levels at approximately equal intervals between 20 % and 100 % of the maximum value of the calibrated range.

If a calibration is conducted at a force below 20 % of the range's upper limit, supplementary force measurements shall be made. Five or more different calibration forces shall be selected for each complete decade below 20 % of the range's upper limit such that the ratio between two adjacent calibration forces is nominally less than or equal to 2. For example: approximately 10 %, 7 %, 4 %, 2 %, 1 %, 0,7 %, 0,4 %, 0,2 %, 0,1 %, etc. of the range's upper limit down to and including the lower limit of calibration. The lowest decade may not be a complete decade and does not require five calibration points.

The lower limit of the range shall not be less than r multiplied by:

— 400 for class 0,5;

— 200 for class 1;

— 100 for class 2;

— 67 for class 3.

For testing machines with auto-ranging indicators, at least two force steps shall be applied on each part of the range where the resolution does not change.

The force-proving instrument may be rotated through an angle of 120° before each series of measurements and a preload run undertaken.

For each discrete force, the relative indication error and the relative repeatability error of the force-measuring system of the testing machine shall be calculated (see 6.5).

The indicator reading shall be set to zero before each series of measurements. The zero reading shall be taken approximately 30 s after the force is completely removed. In the case of an analogue indicator, it shall also be checked that the pointer balances freely around zero and, if a digital indicator is used, that any sub-zero value is clearly displayed, for example by a negative sign indicator.

The relative zero error of each series calculated shall be noted using the following equation:

$$f_0 = \frac{F_{i0}}{F_N} \times 100 \qquad (5)$$

6.4.6 Verification of accessories

The good working order and resistance due to friction of the mechanical accessory devices (pointer, recorder) shall be verified by one of the following methods according to whether the machine is normally used with or without accessories:

a) machine normally used with the accessories: three series of measurements shall be made with increasing force (see 6.4.5) with the accessories connected for each force range used and one complementary series of measurements, without accessories, for the smallest range used.

b) machine normally used without accessories: three series of measurements shall be made with increasing force (see 6.4.5) with the accessories disconnected for each force range used and one complementary series of measurements with the accessories connected for the smallest range used.

In both cases the relative indication error, q, shall be calculated for the three normal series of measurements, and the relative repeatability error, b, shall be calculated from the four series. The values obtained for b and q shall conform to those listed in Table 2 for the class under consideration, and the following further conditions shall be satisfied:

— for calibration with constant indicated force:

$$100\left|\frac{F_\mathrm{i}-F_\mathrm{c}}{F_\mathrm{c}}\right| \leq 1{,}5\ q_\mathrm{al} \qquad (6)$$

— for calibration with constant reference force:

$$100\left|\frac{F_\mathrm{ic}-F}{F}\right| \leq 1{,}5\ q_\mathrm{al} \qquad (7)$$

In the above equations, the value of q_al is the maximum permissible value given in Table 2 for the class under consideration.

6.4.7 Verification of the effect of differences in piston positions

For hydraulic machines, where the hydraulic pressure at the actuator is used to measure the test force, the influence of a difference in position of the piston shall be verified for the smallest measuring range of the machine used during the three series of measurements (see 6.4.5). The position of the piston shall be different for each series of measurements.

In the case of a double-piston hydraulic machine, it is necessary to consider both pistons.

6.4.8 Determination of relative reversibility error

When required, the relative reversibility error, v, shall be determined by carrying out a calibration at the same discrete levels of force, first with increasing force levels and then with decreasing force levels. In this case, the calibration shall be performed using a force-proving instrument calibrated for descending forces in accordance with ISO 376. Only one series of measurements with decreasing force levels is required to determine reversibility error.

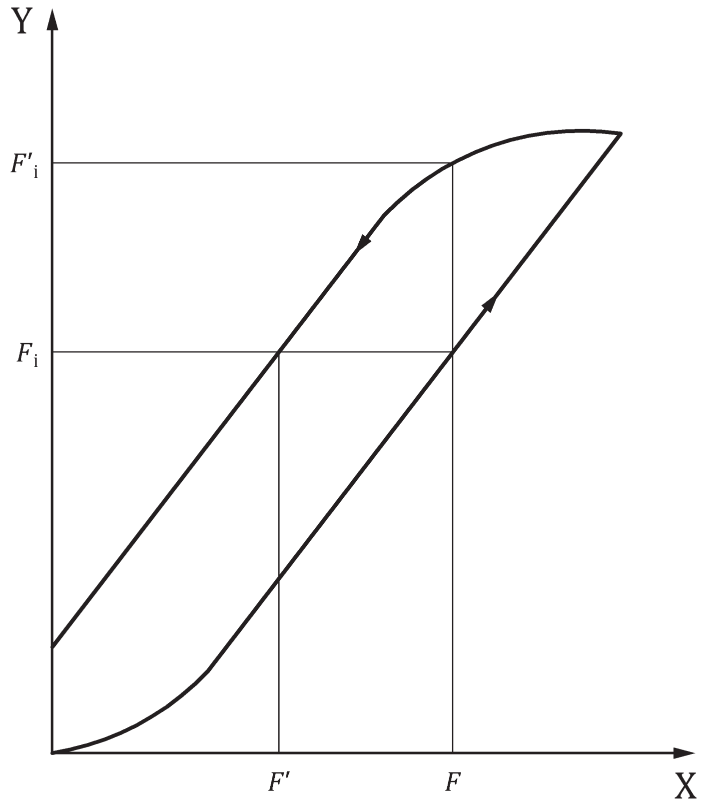
The difference between the values obtained with increasing force and with decreasing force enables the relative reversibility error to be calculated (see Figure 1), using the following equation:

$$v = \frac{F - F'}{\bar{F}} \times 100 \qquad (8)$$

or, for the particular case of the calibration carried out with a constant reference force:

$$v = \frac{F_\mathrm{i}{}' - F_\mathrm{i}}{F} \times 100 \qquad (9)$$

This determination shall be carried out for the lowest and highest force ranges of the testing machine.



Key

X Reference force

Y Force reading on the force indicator of the testing machine

Figure 1 — Schematic diagram for the determination of reversibility

6.5 Assessment of the force indicator

6.5.1 Relative indication error

At each force level calibrated, calculate the relative indication error for each of the three series of measurements as follows:

$$q_1 = \frac{\left(F_{i1} - F_1\right)}{F_1} \times 100 \tag{10}$$

$$q_2 = \frac{\left(F_{i2} - F_2\right)}{F_2} \times 100 \tag{11}$$

$$q_3 = \frac{\left(F_{i3} - F_3\right)}{F_3} \times 100 \tag{12}$$

$$q = \frac{\left(q_1 + q_2 + q_3\right)}{3} \tag{13}$$

The subscripts 1, 2 and 3 represent the readings and calculated values from the three series of runs at each force level.

6.5.2 Relative repeatability error

The relative repeatability error, b, for each discrete force, is the difference between q_{max} and q_{min}. It is given by the equation:

$$b = q_{max} - q_{min} \tag{14}$$

where

q_{max} is the algebraic maximum value of q_1, q_2, and q_3 ;

q_{min} is the algebraic minimum value of q_1, q_2, and q_3.

6.5.3 Agreement between two force-proving instruments

When two force-proving instruments are required to calibrate a measuring range and the same nominal force is separately applied to both (see 6.1), the magnitude of the difference between the relative indication errors obtained with each instrument shall not exceed the magnitude of the repeatability corresponding to the class of machine given in Table 2, i.e.

$$\left| q_{T1} - q_{T2} \right| \leq b_{al} \tag{15}$$

where

q_{T1} is the relative indication error using force-proving instrument 1;

q_{T2} is the relative indication error using force-proving instrument 2;

b_{al} is the allowable repeatability from Table 2.

As an alternative method, the uncertainty of each set of values taken with each force-proving instrument can be evaluated and compared to the differences in the accuracies determined with each instrument as follows:

$$\left| q_{T1} - q_{T2} \right| \leq \sqrt{U_{T1}^2 + U_{T2}^2} \tag{16}$$

where U_{T1} and U_{T2} represent the relative expanded uncertainty expressed in percentages of the measurements made at the same nominal force with force-proving instrument 1 and force-proving instrument 2 respectively.

7 Class of testing machine range

Table 2 gives the maximum permissible values for the different relative errors of the force-measuring system and for the relative resolution of the force indicator, which characterize a testing machine range in accordance with the appropriate class.

Where applicable, the classification of a machine for all force ranges will be limited by the classification obtained for the “verification of accessories” the “verification of the effect of differences in piston positions”, or the “relative reversibility error”.

A measuring range on the force indicator shall only be considered to conform if the verification is satisfactory for the range of measurement at least between 20 % and 100 % of the maximum value of the calibrated range.

Table 2 — Characteristic values of the force-measuring system

Class of machine range	Maximum permissible value %				
	Relative error of				Relative resolution
	indication	repeatability	reversibility[a]	zero	
	q	b	v	f_0	a
0,5	±0,5	0,5	±0,75	±0,05	0,25
1	±1,0	1,0	±1,5	±0,1	0,5
2	±2,0	2,0	±3,0	±0,2	1,0
3	±3,0	3,0	±4,5	±0,3	1,5

[a] According to 6.4.8, the relative reversibility error is only determined when required.

The requirements of this International Standard limit the major components of uncertainty when calibrating testing machines. By complying with this metrological standard, uncertainty is explicitly taken into account as required by some accreditation standards. Reducing the allowable accuracy by the amount of the uncertainty would result in double counting of the uncertainty. The classification of a testing machine calibrated and certified to meet a specific class does not ensure that the accuracy including uncertainty will be less than a specific value. For example, a testing machine meeting Class 0,5 does not necessarily have an accuracy including uncertainty of less than 0,5 %.

8 Verification report

8.1 General

The verification report shall contain at least the following information.

8.2 General information

a) reference to this part of ISO 7500, i.e. ISO 7500-1;

b) identification of the testing machine (manufacturer, type, year of manufacture if known, serial number) and, if applicable, specific identification of the force indicator (manufacturer, type, serial number);

c) location of the machine;

d) type, class and reference number of the force-proving instrument used, calibration certificate number and expiration date of the certificate;

e) calibration temperature;

f) date of verification;

g) name or mark of the verifying authority.

8.3 Results of verification

The results of verification shall mention:

a) any anomaly found during the general inspection;

b) for each force-measuring system used, the mode of calibration (tension, compression, tension/compression), the class of each range calibrated and, if requested, the discrete values of relative errors of indication, repeatability, reversibility, zero and resolution;

c) the lower limit of each range to which the assessment applies.

9 Intervals between verifications

The time between two verifications depends on the type of testing machine, the standard of maintenance and the amount of use. Unless otherwise specified, it is recommended that verification be carried out at intervals not exceeding 12 months.

The machine shall in any case be verified if it is moved to a new location necessitating dismantling or if it is subject to major repairs or adjustments.

Annex A
(normative)

General inspection of the testing machine

A.1 General

The general inspection of the testing machine (see Clause 5) shall be carried out before the calibration of the force-measuring system and shall comprise the following.

A.2 Visual examination

The visual examination shall verify:

a) that the machine is in good working order and not adversely affected by certain aspects of its general condition, such as

   1) pronounced wear or defects in the guiding elements of the moving crosshead or grips;

   2) looseness in the columns' mountings and in the fixed crosshead;

b) that the machine is not affected by environmental conditions (vibrations, electrical supply interferences, effects of corrosion, local temperature variations, etc.);

c) that the masses are correctly identifiable, if detachable mass pendulum devices are used.

A.3 Inspection of the structure of the machine

A check shall be made to ensure that the structure and gripping systems permit the force to be applied axially.

A.4 Inspection of the crosshead drive mechanism

It shall be verified that the crosshead drive mechanism permits a uniform and smooth variation of force and can enable various discrete forces to be obtained with sufficient accuracy.

Annex B
(informative)

Inspection of the loading platens of the compression testing machines

Loading platens are either permanently installed in the machine or they are specific components of the testing machine.

It should be verified that the loading platens perform their function in accordance with the requirements of the testing machine.

Unless other requirements are specified in certain test standards, the maximum flatness deviation should be 0,01 mm measured over 100 mm.

When the platen is made of steel, the hardness should be greater than or equal to 55 HRC.

For machines used for testing specimens sensitive to bending stresses, it should be checked whether the upper platen is carried in a cup and ball seat which, in the unloaded state, is practically without play and easy to adjust to an angle of up to approximately 3°.

Annex C
(informative)

Uncertainty of the calibration results of the force-measuring system

C.1 Introduction

It is possible to calculate the uncertainty of the force-measuring system at the time of calibration, either from the specification limits or from the readings obtained. These calculations are detailed in the following sections.

Typically, the indication error, q, as a known bias, is not corrected during calibration, if it falls within specifications of Table 2. Therefore the range within which the estimated relative error, E, could reasonably be expected to lie should be $E = q \pm U$, where q is the relative indication error defined in 6.5.1 and U is the expanded uncertainty.[3]

C.2 Incremental forces

C.2.1 Estimate of the relative mean error

The best estimate of the relative mean error in the force indicated by the testing machine is q, the relative indication error. Associated with this estimate of the relative mean error is an expanded uncertainty, U, given by:

$$U = k \times u_\mathrm{c} = k \times \sqrt{\sum_{i=1}^{n} u_i^2} \tag{C.1}$$

where

k is the coverage factor;

u_c is the combined uncertainty;

u_1 to u_n are the relevant standard uncertainties.

u_1 to u_n include terms related to repeatability, resolution and the transfer standard. Other uncertainty contributions which need to be considered may include end-loading (force introduction) effects and the influence of the operator.

C.2.2 Repeatability

The standard uncertainty related to repeatability, u_rep, is the standard deviation of the estimated relative mean error value:

$$u_\mathrm{rep} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} \left(q_i - q\right)^2} \tag{C.2}$$

where

n is the number of readings at each nominal force level;

q_i is the measured error at the nominal force level (%);

q is the mean measured error at the nominal force level (%).

C.2.3 Resolution

The uncertainty due to the resolution of the testing machine at each calibration force is the square root of the sum-of-the-squares of the following two components:

— the uncertainty component due to the resolution of the machine's indication at the applied force, given by the relative resolution a_F divided by two times the square root of three and

— the uncertainty component due to the resolution of the machine's indication at zero force, given by the relative resolution a_z [calculated as in 6.3 and using the calibration force as F_i in Formula (4)] divided by two times the square root of three.

The total uncertainty due to resolution is:

$$u_{res} = \sqrt{\left(\frac{a_F}{2\sqrt{3}}\right)^2 + \left(\frac{a_z}{2\sqrt{3}}\right)^2} \tag{C.3}$$

C.2.4 Transfer standard

The standard uncertainty related to the transfer standard, u_{std}, is given by:

$$u_{std} = \sqrt{u_{cal}^2 + A^2 + B^2 + C^2} \tag{C.4}$$

where

u_{cal} is the relative standard's calibration uncertainty;

A, B and C are, where relevant, contributions due to temperature, drift and linear approximation to the polynomial curve.

C.2.5 Expanded uncertainty

Once all the relevant standard uncertainties have been allowed for (including the other contributions mentioned above), the combined uncertainty, u_c, is multiplied by a coverage factor, k, to give the expanded uncertainty, U. It is recommended that a value of $k = 2$ be used, although k may also be calculated from the number of effective degrees of freedom. The principles laid down in Reference [3] should be adhered to.

The estimated mean relative error, E, could reasonably be expected to lie within the range:

$$E = q \pm U \tag{C.5}$$

and the mean generated force, F, can be expressed as:

$$F \approx F_i - \frac{F_i}{100}(q \pm U) \tag{C.6}$$

C.3 Decremental forces

For decremental forces, the combined uncertainty, u_c', is calculated from the uncertainty contributions of q and v. The uncertainty contribution of v is assumed to be the same as that of the incremental indication error q. The combined uncertainty, u_c', is thus estimated as:

$$u_c{}' = \sqrt{2} \times u_c \tag{C.7}$$

The combined uncertainty, u_c', is multiplied by a coverage factor, k, to give the expanded uncertainty, U'. The estimated mean relative error, E', could reasonably be expected to lie within the range:

$$E' = \left(q + v\right) \pm U' \tag{C.8}$$

where

q is the incremental relative indication error;

v is the relative reversibility error.

The mean generated decremental force, F', can be expressed as:

$$F' \approx F_i{}' - \frac{F_i{}'}{100}\left[\left(q + v\right) \pm U'\right] \tag{C.9}$$

EXAMPLE

- indicated force: 100,0 kN, resolution 0,5 kN
- measured incremental forces (runs 1 to 3): 100,1 kN, 100,8 kN, and 100,9 kN
- measured decremental force (run 4): 99,5 kN
- class 1 transfer standard (u_{std} = 0,12 %)
- no significant drift, temperature, or fit effects
- no significant end-loading or operator influence effects
- relative indication error q = − 0,60 %: meets class 1 criteria
- relative repeatability error b = 0,80 %: meets class 1 criteria
- relative reversibility error v = + 1,39 %: meets class 1 criteria
- relative resolution a = 0,50 %: meets class 1 criteria
- u_{rep} = 0,25 % (standard deviation of mean estimated error)
- u_{res} = 0,20 % (standard uncertainty of resolution)
- u_{std} = 0,12 % (standard uncertainty of standard's calibration)
- u_c = 0,34 % (root sum squares combination of u_{rep}, u_{res}, and u_{std})
- u_c' = 0,48 % (root sum squares combination of the incremental and decremental components)
- U = 0,68 % (product of combined uncertainty and k = 2)
- U' = 0,96 % (product of incremental and decremental combined uncertainty and k = 2)
- $E = \left(-0{,}60 \pm 0{,}68\right)$ % (expected range of mean incremental error)

— $F \approx \left[F_{\text{i}} - \frac{F_{\text{i}}}{100} \left(-0{,}60 \pm 0{,}68 \right) \right]$ kN (expected range of mean incremental force)

— $E' = -0,60 + 1,39 \pm 0,96 = \left(0,79 \pm 0,96 \right)$ % (expected range of mean decremental error)

— $F' \approx \left[F_{\text{i}}{}' - \frac{F_{\text{i}}{}'}{100} \left(0,79 \pm 0,96 \right) \right]$ kN (expected range of mean decremental force)

NOTE The above procedure results only in uncertainties of the mean indicated error obtained during the calibration of the testing machine. It does not give the uncertainty associated with a single application of force during the calibration, nor does it represent the uncertainty of the machine during its subsequent use when many other factors are to be considered (e.g. specimen alignment, temperature drift, fixtures).

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