# Annex D: Mechanical measurements (normative)

## D1 Force calibrations

### D1.1 General

The purpose of this section is to specify the technical criteria that shall be met when performing calibrations of force-measuring instruments.

### D1.2 Procedural standard methods

All measurement procedures, accommodation and environmental conditions, instruments and equipment used, and the reporting of results when conducting a force-related calibration, shall comply with one or both of the following referenced standards documents, except in special circumstances (see below):

ASTM E74, *Standard Practices of Calibration and Verification of Force-Measuring Instruments*

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

*Special circumstances*: Laboratories may be accredited to other documentary standards methods or laboratory-developed methods once they have been assessed for them.

### D1.3 Accommodation and environmental conditions

**D1.3.1** All instruments shall be allowed sufficient time to reach room temperature prior to calibration.

**D1.3.2** The recommended calibration temperature is 23 °C (73.4 °F), however, calibrations shall be conducted within the temperature ranges specified by the procedural method used.

**D1.3.3** During calibration, the temperature shall be monitored at a location that reflects the temperature of the instrument.

**D1.3.4** Temperature stability shall be maintained in accordance with the procedural method used.

**D1.3.5** If the temperature variations exceed ± 0.2 °C during the calibrations of non-temperature compensated instruments such as proving rings, the calibration data shall be corrected in accordance with the applicable force calibration standard.

### D1.4 Equipment

#### D1.4.1 Primary force standards (ASTM E74)

**D1.4.1.1** A laboratory that performs primary force standards calibrations shall directly apply a deadweight force without intervening mechanisms such as levers, hydraulic multipliers, or the like, whose mass has been determined by comparison with mass reference standards traceable to the International System of Units (SI).

**D1.4.1.2** Primary force standard deadweight machines shall not have any mechanism for amplifying the force such as levers, hydraulic multipliers or the like, or any mechanism that counterbalances the frame (or tare).

**D1.4.1.3** Weights used as primary standards in deadweight machines shall be made of rolled, forged, or cast metal.

**D1.4.1.4** The surface roughness of the weights shall meet the requirements of the applicable force calibration standard.

**D1.4.1.5** If the weights are plated or coated, the finish shall be of a proven design and of a material such as cadmium or nickel-chromium.

**D1.4.1.6** The forces developed by the weights shall be determined using formula 1,

$$F = mg[1 - (\rho_a/\rho_w)], \quad (1)$$

where

$F$ = force (N),

$m$ = mass (kg),

$g$ = local acceleration due to gravity (m/s$^2$),

$\rho_a$ = density of air, and

$\rho_w$ = density of the weight (same units as $\rho_a$).

**D1.4.1.7** This requires that the laboratory shall have knowledge of the local gravity, its uncertainty, and the local air buoyancy correction.

**D1.4.1.8** The masses of the weights shall be known to within 0.005 % of their nominal values by comparison to reference standards traceable to the International System of Units (SI). The local value of the acceleration due to gravity, calculated within 0.0001 m/s$^2$ (10 mGal), may be obtained from the National Geodetic Information Center, National Oceanic and Atmospheric Administration.

**D1.4.1.9** The laboratory shall keep records of the calibration of all weights used as standards.

**D1.4.1.10** The uncertainty of the vertical component of force applied by the weights shall also be stated in the laboratory records and in reports of calibration.

**D1.4.1.11** The masses of the weights shall be determined initially and the determination repeated if damage or disassembly of the machine occurs.

**D1.4.1.12** Verification of force realization shall be demonstrated through an intercomparison program as outlined by the laboratory's quality system.

### D1.4.2 Secondary force standards (ASTM E74)

**D1.4.2.1** Secondary force standards shall have been calibrated against primary force standards, with the exception that secondary force standards having capacities exceeding 1 000 000 lbf (4.4 MN) may be calibrated against a combination of several lower-capacity secondary force standards loaded in parallel.

**D1.4.2.2** If several secondary force standards are combined and loaded in parallel to meet special needs for high capacities exceeding 1 000 000 lbf (4.4 MN):

a) those secondary force standards shall have equal compliance, and

b) forces shall be applied equally to each of those secondary force standards.

**D1.4.2.3** Secondary force standards used shall have a suitable force calibration frame or mechanism to ensure an axial force application to the unit under test. The secondary system should exhibit no parasitic, frictional or mechanical losses during use.

**D1.4.2.4** Any perturbations shall have been characterized.

#### D1.4.3 Uncertainty of the applied forces

The uncertainty of the applied forces generated shall be determined using appropriate methods, such as recommended in ASTM E74 and ISO 376.

#### D1.4.4 Overloaded or repaired instruments

**D1.4.4.1** Any force standard or multiplying system that is repaired or modified in a way that may result in changes in the calibration curve shall be recalibrated prior to use.

**D1.4.4.2** Any instrument that sustains an overload that produces a change in the zero-force output of 1 % or more shall be recalibrated prior to use.

#### D1.4.5 Accessory hardware

All calibration hardware that is subject to calibration forces such as coupling nuts, pull-rods, adapters, etc., shall be clearly labelled with the maximum allowable force they can sustain.

#### D1.4.6 Electrical instruments

The electrical instrumentation used to calibrate force-measuring instrumentation shall comply with the requirements specified by the procedural method used.

### D1.5 Calibration

#### D1.5.1 Distribution and number of calibration forces

The calibration forces shall be distributed over the full range of the force-measuring instrument as specified by the procedural method used. Note that the requirements of ASTM E74 and ISO 376 differ.

#### D1.5.2 Randomization of force application conditions

Randomization of force application conditions is of primary importance. The instrument undergoing calibration shall be rotated in the calibration machine and subjected to other randomizations in accordance with the procedural method used.

## D1.6 Records

All measurements shall be appropriately recorded and maintained in accordance with the procedural method used where those requirements exceed those of ISO/IEC 17025.

## D1.7 Reporting the results

**D1.7.1** In addition to the report requirements of ISO/IEC 17025, the laboratory shall provide calibration reports that conform to the requirements of ASTM E74, ISO 376 or both.

**D1.7.2** The calibration report shall state which documentary standard(s) was (were) followed.

**D1.7.3** In cases where other procedural standards are followed, the calibration report shall, at a minimum, contain the following information:

a) manufacturer and serial number of the instrument calibrated;

b) type of reference standard used (i.e., primary standard, secondary standard), including the uncertainty in the applied force;

c) if critical to transducer performance, identification of the force application fittings used;

d) temperature at which the calibration was performed, including limits of temperatures variations during the calibrations;

e) listing of the calibration forces applied and deflections observed;

f) the calibration curve, including the method of analysis used to obtain the curve, and the deviations of the experimental data for the fitted curve;

g) the uncertainty associated with the calibration results and limits of assigned force ranges if such limits are required.