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Metallic materials — Charpy pendulum impact test —

Part 2:
Verification of testing machines

Matériaux métalliques — Essai de flexion par choc sur éprouvette Charpy —

Partie 2: Vérification des machines d'essai (mouton-pendule)

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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.

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 148-2 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing — Fracture (F), Pendulum (P), Tear (T)*.

This second edition cancels and replaces the first edition (ISO 148-2:1998), which has been technically revised.

ISO 148 consists of the following parts, under the general title *Metallic materials — Charpy pendulum impact test*:

— *Part 1: Test method*

— *Part 2: Verification of testing machines*

— *Part 3: Preparation and characterization of Charpy V-notch test pieces for indirect verification of pendulum impact machines*

Introduction

The suitability of a pendulum impact testing machine for acceptance testing of metallic materials has usually been based on a calibration of its scale and verification of compliance with specified dimensions, such as the shape and spacing of the anvils supporting the specimen. The scale calibration is commonly verified by measuring the mass of the pendulum and its elevation at various scale readings. This procedure for evaluation of machines had the distinct advantage of requiring only measurements of quantities that could be traced to national standards. The objective nature of these traceable measurements minimized the necessity for arbitration regarding the suitability of the machines for material acceptance tests.

However, sometimes two machines that had been evaluated by the direct-verification procedures described above, and which met all dimensional requirements, were found to give significantly different impact values when testing test pieces of the same material. This difference was commercially important when values obtained using one machine met the material specification, while the values obtained using the other machine did not. To avoid such disagreements, some purchasers of materials added the requirement that all pendulum impact testing machines used for acceptance testing of material sold to them must be indirectly verified by testing reference test pieces supplied by them. A machine was considered acceptable only if the values obtained using the machine agreed, within specified limits, with the value furnished with the reference test pieces.

Metallic materials — Charpy pendulum impact test —

Part 2:
Verification of testing machines

1 Scope

This part of ISO 148 covers the verification of the constructional elements of pendulum-type impact testing machines. It is applicable to machines with 2 mm or 8 mm strikers used for pendulum impact tests carried out, for instance, in accordance with ISO 148-1.

It can analogously be applied to pendulum impact testing machines of various capacities and of different design.

Impact machines used for industrial, general or research laboratory testing of metallic materials in accordance with this part of ISO 148 are referred to as industrial machines. Those with more stringent requirements are referred to as reference machines. Specifications for the verification of reference machines are found in ISO 148-3.

This part of ISO 148 describes two methods of verification.

a) The direct method, which is static in nature, involves measurement of the critical parts of the machine to ensure that it meets the requirements of this part of ISO 148. Instruments used for the verification and calibration are traceable to national standards. Direct methods are used when a machine is being installed or repaired, or if the indirect method gives a non-conforming result.

b) The indirect method, which is dynamic in nature, uses reference test pieces to verify points on the measuring scale.

A pendulum impact testing machine is not in compliance with this part of ISO 148 until it has been verified by both the direct and indirect methods and meets the requirements of Clauses 6 and 7.

The requirements for the reference test pieces are found in ISO 148-3.

This part of ISO 148 takes into account the total energy absorbed in fracturing the test piece using an indirect method. This total absorbed energy consists of

— the energy needed to break the test piece itself, and

— the internal energy losses of the pendulum impact testing machine performing the first half-cycle swing from the initial position.

NOTE Internal energy losses are due to

— air resistance, friction of the bearings of the rotation axis and of the indicating pointer of the pendulum which can be determined by the direct method (see 6.4.5), and

— shock of the foundation, vibration of the frame and pendulum for which no suitable measuring methods and apparatus have been developed.

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 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 148-3, *Metallic materials — Charpy pendulum impact test — Part 3: Preparation and characterization of Charpy V-notch test pieces for indirect verification of pendulum impact machines*

3 Terms and definitions

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

3.1 Definitions pertaining to the machine

3.1.1
anvil
portion of the machine that serves to properly position the test piece for impact with respect to the striker and the test piece supports, and supports the test piece under the force of the strike

3.1.2
base
that part of the framework of the machine located below the horizontal plane of the supports

3.1.3
centre of percussion
that point in a body at which, on striking a blow, the percussive action is the same as if the whole mass of the body were concentrated at the point

NOTE When a simple pendulum delivers a blow along a horizontal line passing through the centre of percussion, there is no resulting horizontal reaction at the axis of rotation.

See Figure 4.

3.1.4
centre of strike
that point on the striking edge of the pendulum at which, in the free hanging position of the pendulum, the vertical edge of the striker meets the upper horizontal plane of a test piece of half standard height (i.e. 5 mm) or equivalent gauge bar resting on the test piece supports

See Figure 4.

3.1.5
industrial machine
pendulum impact machine used for industrial, general, or most research-laboratory testing of metallic materials

NOTE 1 These machines are not used to establish reference values.

NOTE 2 Industrial machines are verified using the procedures described in this part of ISO 148.

3.1.6
reference machine
pendulum impact testing machine used to determine certified values for batches of reference test pieces

3.1.7
striker
portion of the pendulum that contacts the test piece

NOTE The edge that actually contacts the test piece has a radius of 2 mm (the 2 mm striker) or a radius of 8 mm (the 8 mm striker).

See Figure 2.

3.1.8
test piece supports
portion of the machine that serves to properly position the test piece for impact with respect to the centre of percussion of the pendulum, the striker and the anvils

See Figures 2 and 3.

3.2 Definitions pertaining to energy

3.2.1
total absorbed energy
K_T
total absorbed energy required to break a test piece with a pendulum impact testing machine, which is not corrected for any losses of energy

NOTE It is equal to the difference in the potential energy from the starting position of the pendulum to the end of the first half swing during which the test piece is broken (see 6.3).

3.2.2
initial potential energy
potential energy
K_P
difference between the potential energy of the pendulum hammer prior to its release for the impact test, and the potential energy of the pendulum hammer at the position of impact, as determined by direct verification

NOTE See 6.4.2.

3.2.3
absorbed energy
K
energy required to break a test piece with a pendulum impact testing machine, after correction for friction

NOTE The letter V or U is used to indicate the notch geometry, that is KV or KU. The number 2 or 8 is used as a subscript to indicate striker radius, for example KV_2.

3.2.4
calculated energy
K_{calc}
energy calculated from values of angle, length, and force measured during direct verification

3.2.5
nominal initial potential energy
nominal energy
K_N
energy assigned by the manufacturer of the pendulum impact testing machine

3.2.6
indicated absorbed energy
K_S
energy indicated by the display/dial of the testing machine, which may or may not need to be corrected for friction to determine absorbed energy, K

3.2.7
reference absorbed energy
K_R
certified value of absorbed energy assigned to the test pieces used to verify the performance of pendulum impact machines

3.3 Definitions pertaining to test pieces

3.3.1
height
distance between the notched face and the opposite face

3.3.2
width
dimension perpendicular to the height that is parallel to the notch

3.3.3
length
largest dimension perpendicular to the notch

3.3.4
reference test piece
impact test piece used to verify the suitability of pendulum impact testing machines by comparing the indicated absorbed energy measured by that machine to the reference absorbed energy associated with the test pieces

NOTE Reference test pieces are prepared in accordance with ISO 148-3.

4 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in Table 1 are applicable.

Table 1 — Symbols/abbreviated terms and their designations and units

Symbol/ abbreviated term [a]	Unit	Designation
B_V	J	Bias of the pendulum impact machine as determined through indirect verification
b	J	Repeatability
F	N	Force exerted by the pendulum when measured at a distance of l_2
F_g	N	Force exerted by the pendulum due to gravity
g	m/s^2	Acceleration due to gravity
GUM	—	Guide to the expression of uncertainty in measurement
h	m	Height of fall of pendulum
H_1	m	Height of rise of pendulum
ISO	—	International Organization for Standardization
KV	J	Absorbed energy as measured in accordance with ISO 148 on a V-notched sample
KV_R	J	Certified KV value of the reference material used in the indirect verification
$\overline{KV}_V$	J	Mean KV value of the reference test pieces tested for indirect verification
K_N	J	Nominal initial potential energy (nominal energy)
K_P	J	Initial potential energy (potential energy)
K_R	J	Reference absorbed energy of a set of Charpy reference test pieces

Table 1 (*continued*)

Symbol/ abbreviated term [a]	Unit	Designation
K	J	Absorbed energy (expressed as KV_2, KV_8, KU_2, KU_8, to identify specific notch geometries and striker radii)
K_T	J	Total absorbed energy
K_S	J	Indicated absorbed energy
K_{calc}	J	Calculated energy
K_1 or β_1	J or degree	Indicated absorbed energy or angle of rise when the machine is operated in the normal manner without a test piece in position
K_2 or β_2	J or degree	Indicated absorbed energy or angle of rise when the machine is operated in the normal manner without a test piece in position and without resetting the indication mechanism
K_3 or β_3	J or degree	Indicated absorbed energy or angle of rise after 11 half swings when the machine is operated in the normal manner without a test piece in position and without resetting the indication mechanism
l	m	Distance to centre of test piece (centre of striker) from the axis of rotation (length of pendulum)
l_1	m	Distance to the centre of percussion from the axis of rotation
l_2	m	Distance to the point of application of the force F from the axis of rotation
M	N·m	Moment equal to the product Fl_2
n_V	—	Number of reference samples tested for the indirect verification of a pendulum impact testing machine
p	J	Absorbed energy loss caused by pointer friction
p'	J	Absorbed energy loss caused by bearing friction and air resistance
p_β	J	Correction of absorbed energy losses for an angle of swing β
r	J	Resolution of the pendulum scale
RM	—	Reference material
s_V	J	Standard deviation of the KV values obtained on n_V reference samples
S	J	Bias in the scale mechanism
t	s	Period of the pendulum
T	s	Total time for 100 swings of the pendulum
T_{max}	s	Maximum value of T
T_{min}	s	Minimum value of T
$u(\overline{KV}_V)$	J	Standard uncertainty of $\overline{KV}_V$
$u(B_V)$	J	Standard uncertainty contribution from bias
$u(F)$	J	Standard uncertainty of the measured force, F
$u(F_{std})$	J	Standard uncertainty of the force transducer
$u(r)$	J	Standard uncertainty contribution from resolution
u_{RM}	J	Standard uncertainty of the certified value of the reference material used for the indirect verification
u_V	J	Standard uncertainty of the indirect verification result
α	degree	Angle of fall of the pendulum
β	degree	Angle of rise of the pendulum
ν_B	—	Degrees of freedom corresponding to $u(B_V)$
ν_V	—	Degrees of freedom corresponding to u_V
ν_{RM}	—	Degrees of freedom corresponding to u_{RM}

[a] See Figure 4.

5 Testing machine

A pendulum impact testing machine consists of the following parts (see Figures 1 to 3):

a) foundation/installation;

b) machine framework — the structure supporting the pendulum, excluding the foundation;

c) pendulum, including the hammer;

d) anvils and supports (see Figures 2 and 3);

e) indicating equipment for the absorbed energy (e.g. scale and friction pointer or electronic readout device).

6 Direct verification

6.1 General

Direct verification of the machine involves the inspection of the following items:

a) foundation/installation;

b) machine framework;

c) pendulum, including the hammer and the striker;

d) anvils and supports;

e) indicating equipment.

6.2 Foundation/installation

6.2.1 The foundation to which the machine is fixed and the method(s) of fixing the machine to the foundation are of utmost importance.

6.2.2 Inspection of the machine foundation can usually not be made once the machine has been installed; thus, documentation made at the time of installation shall be produced to provide assurance that the mass of the foundation is not less than 40 times that of the pendulum.

6.2.3 Inspection of the installed machine shall consist of the following:

a) ensuring that the bolts are torqued to the value specified by the machine manufacturer. The torque value shall be noted in the document provided by the manufacturer of the machine (see 6.2.1). If other mounting arrangements are used or selected by an end user, equivalency shall be demonstrated;

b) ensuring that the machine is not subject to external vibrations transmitted through the foundation at the time of the impact test.

NOTE This can be accomplished, for example, by placing a small container of water on any convenient location on the machine framework. The absence of ripples on the water surface indicates that this requirement has been met.

6.3 Machine framework

6.3.1 Inspection of the machine framework (see Figure 1) shall consist of determining the following items:

a) free position of the pendulum;

b) location of the pendulum in relation to the supports;

c) transverse and radial play of the pendulum bearings;

d) clearance between the hammer and the framework.

Machines manufactured after the original publication date of this part of ISO 148 shall have a reference plane from which measurements can be made. Annex C, based on EN 10045-2, is provided for information.

6.3.2 The axis of rotation of the pendulum shall be parallel to the reference plane to within 2/1 000. This shall be certified by the manufacturer.

6.3.3 The machine shall be installed so that the reference plane is horizontal to within 2/1 000.

For pendulum impact testing machines without a reference plane, the axis of rotation shall be established to be horizontal to within 4/1 000 directly or a reference plane shall be established from which the horizontality of the axis of rotation can be verified as described above.

6.3.4 When hanging free, the pendulum shall hang so that the striking edge is within 0,5 mm of the position where it would just touch the test specimen.

NOTE This condition can be determined using a gauge in the form of a bar, approximately 55 mm in length and of rectangular section, 9,5 mm in height and approximately 10 mm in width (see Figure 3). The distance between the striker and the bar is then measured.

6.3.5 The plane of the swing of the pendulum shall be 90° ± 0,1° to the axis of rotation.

6.3.6 The striker shall make contact over the full width of the test piece.

NOTE One method of verifying this is as follows.

A test piece having dimensions of 55 mm × 10 mm × 10 mm is tightly wrapped in thin paper (e.g. by means of adhesive tape), and the test piece is placed in the test-piece supports. Similarly, the striker edge is tightly wrapped in carbon paper with the carbon side outermost (i.e. not facing the striker). From its position of equilibrium, the pendulum is raised a few degrees, released so that it contacts the test piece, and prevented from contacting the test piece a second time. The mark made by the carbon paper on the paper covering the test piece should extend completely across the paper. This test may be performed concurrently with that of checking the angle of contact between the striker and the test piece (see 6.4.8).

6.3.7 The pendulum shall be located so that the centre of the striker and the centre of the gap between the anvils are coincident to within 0,5 mm.

6.3.8 Axial play in the pendulum bearings shall not exceed 0,25 mm measured at the striker under a transverse force of approximately 4 % of the effective weight of the pendulum, F_g [see Figure 4 b)], applied at the centre of strike.

6.3.9 Radial play of the shaft in the pendulum bearings shall not exceed 0,08 mm when a force of 150 ± 10 N is applied at a distance l perpendicular to the plane of swing of the pendulum.

NOTE The radial play can be measured, for example, by a dial gauge mounted on the machine frame at the bearing housing in order to indicate movement at the end of the shaft (in the bearings) when a force of about 150 N is applied to the pendulum perpendicularly to the plane of the swing.

6.3.10 For new machines, it is recommended that the mass of the base of the machine framework be at least 12 times that of the pendulum.

NOTE The base of the machine is that portion of the framework located below the plane(s) of the supports.

6.4 Pendulum

6.4.1 The verification of the pendulum (including striker) shall consist of determining the following quantities:

a) potential energy, K_P;

b) error in the indicated absorbed energy, K_S;

c) velocity of the pendulum at instant of impact;

d) energy absorbed by friction;

e) position of centre of percussion (i.e. distance from centre of percussion to axis of rotation);

f) striker radius;

g) angle between the line of contact of the striker and the horizontal axis of the test piece.

6.4.2 The potential energy, K_P, shall not differ from the nominal energy, K_N, by more than ± 1 %. The potential energy, K_P, shall be determined as follows.

The moment of the pendulum is determined by supporting the pendulum at a chosen distance, l_2, from the axis of rotation by means of a knife edge on a balance or dynamometer in such a manner that the line through the axis of rotation that joins the centre of gravity of the pendulum is horizontal within 15/1 000 [see Figure 4 a)].

The force, F, and the length, l_2, shall each be determined to an accuracy of ± 0,2 %. The moment, M, is the product of $F \times l_2$.

NOTE Length l_2 can be equal to length l.

The angle of fall, α, shall be measured to an accuracy of ± 0,2°; this angle can be greater than 90°.

The potential energy, K_P, is then calculated by Equation (1):

$$K_P = M(1 - \cos\alpha) \tag{1}$$

6.4.3 The graduation marks on the scale corresponding approximately to values of absorbed energy of 0 %, 10 %, 20 %, 30 %, 50 % and 80 % of the nominal energy shall be verified.

For each of these graduation marks, the pendulum shall be supported so that the graduation mark is indicated by the pointer, and the angle of rise, β, then determined to ± 0,2°. The calculated energy is given by Equation (2):

$$K_{calc} = M(\cos\beta - \cos\alpha) \tag{2}$$

NOTE 1 The degree of inaccuracy of measurement of l_2, F and β, as specified, yields a mean total error of measurement of K_{calc} of approximately ± 0,3 % of the full-scale value.

The difference between the indicated absorbed energy, K_S, and the calculated energy from the measured values shall not be greater than ± 1 % of the energy reading or ± 0,5 % of the nominal energy, K_N. In each case, the greater value is permitted, i.e.:

$$\left| \frac{K_{calc} - K_S}{K_S} \right| \times 100 < 1 \text{ \% at between 80 \% and 50 \% of the nominal energy, } K_N \tag{3}$$

$$\left| \frac{K_{calc} - K_S}{K_N} \right| \times 100 < 0{,}5 \text{ \% at less than 50 \% of the nominal energy, } K_N \tag{4}$$

NOTE 2 Attention is drawn to the fact that the accuracy of the absorbed energy reading varies inversely to its value, and this is important when K is small in comparison with K_N.

NOTE 3 For machines with scales and readout devices that are corrected for energy losses, K_{calc} will need to be corrected in order to compare the results properly.

Absorbed energy values greater than 80 % of the potential energy are inaccurate and should be reported as approximate.

NOTE 4 This requirement serves to ensure that all tests are conducted at strain rates that vary by less than a factor of 2. The strain rate is a function of the velocity of the pendulum while the striker is in contact with the specimen; for a pendulum impact testing machine, the velocity decreases as the fracture progresses. The change in the velocity of the pendulum can be calculated by first determining the velocity at impact using Equation (5) and, after impact, by using the same formula except that the cosine of β is substituted for the cosine of α (see Figure 4).

6.4.4 The velocity at impact shall be determined for instance from Equation (5):

$$v = \sqrt{2gl(1-\cos\alpha)} \tag{5}$$

where g may be taken as 9,81 m/s^2 (to save measurement at the site of each testing machine).

The velocity at impact shall be 5 m/s to 5,5 m/s; however, for machines manufactured prior to 1998, any value within the range of 4,3 m/s to 7 m/s is permissible and the value shall be stated in the report.

6.4.5 The energy absorbed by friction includes, but is not limited to, air resistance, bearing friction and the friction of the indicating pointer. These losses shall be estimated as follows.

6.4.5.1 To determine the loss caused by pointer friction, the machine is operated in the normal manner, but without a test piece in position, and the angle of rise, β_1, or energy reading, K_1, noted as indicated by the pointer. A second test is then carried out without resetting the indication pointer and the new angle of rise, β_2, or energy reading, K_2, noted. Thus, the loss due to friction in the indicating pointer during the rise is equal to

$$p = M(\cos\beta_1 - \cos\beta_2) \tag{6}$$

when the scale is graduated in degrees, or

$$p = K_1 - K_2 \tag{7}$$

when the scale is graduated in energy units.

The values of β_1 and β_2 or of K_1 and K_2 shall be the mean values of four determinations.

6.4.5.2 Determination of the losses caused by bearing friction and air resistance for one half swing is performed as follows.

After determining β_2 or K_2 in accordance with 6.4.5.1, the pendulum is put into its initial position. Without resetting the indicating mechanism, release the pendulum without shock and vibration and permit it to swing 10 half swings. After the pendulum starts its 11th half swing, move the indicating mechanism to about 5 % of the scale-range capacity and record the value as β_3 or K_3. The losses by bearing friction and air resistance for one half swing are equal to

$$p' = 1/10\, M(\cos\beta_3 - \cos\beta_2) \tag{8}$$

when the scale is graduated in degrees, or

$$p' = 1/10\, (K_3 - K_2) \tag{9}$$

when the scale is graduated in energy units.

NOTE If it is required to take into account these losses in an actual test giving an angle of rise, β, the quantity

$$p_\beta = p\frac{\beta}{\beta_1} + p'\frac{\alpha+\beta}{\alpha+\beta_2} \tag{10}$$

can be subtracted from the value of the absorbed energy.

Because β_1 and β_2 are nearly equal to α, for practical purposes, it can be reduced to an approximate equation for p_β as follows:

$$p_\beta = p\frac{\beta}{\alpha} + p'\frac{\alpha+\beta}{2\alpha} \tag{11}$$

For machines graduated in energy units, the value of β can be calculated as follows:

$$\beta = \arccos[1 - 1/M(K_P - K_T)] \quad (12)$$

6.4.5.3 The total friction loss $p + p'$, so measured, shall not exceed 0,5 % of the nominal energy, K_N. If it does, and it is not possible to bring the friction loss within the tolerance by reducing the pointer friction, the bearings shall be cleaned or replaced.

6.4.6 The distance from the centre of percussion to the axis of rotation, l_1, is derived from the period (time of swing) of the pendulum, and it shall be 0,995 l ± 0,005 l. The accuracy of the calculated value of l_1 shall be ± 0,5 mm.

The distance can be determined by swinging the pendulum through an angle not exceeding 5°, and measuring the time, t, of a complete swing in seconds.

l_1 is derived from Equation (13):

$$l_1 = \frac{g \cdot t^2}{4\pi^2} \quad (13)$$

where

g is taken as equal to 9,81 m/s^2; however, if the local acceleration of gravity is known or is believed to be significantly different from 9,81 m/s^2, the local acceleration of gravity shall be used;

π^2 is taken as equal to 9,87.

Therefore, in metres, $l_1 = 0{,}248\ 5t^2$.

The value of t shall be determined to within 0,1 %.

NOTE With a pendulum having a period of approximately 2 s, this accuracy may be achieved as follows. Determine the time, T, of 100 complete swings, three times. An accurate measure of t is the average of the three T's divided by 100, provided the quantity ($T_{max} - T_{min}$), which represents the repeatability, is not more than 0,2 s.

6.4.7 The dimensions of the striker shall be checked. Either of two types of striker may be used, the 2 mm striker or the 8 mm striker. The values for the radius of curvature and the angle of the tip for both types are shown in Table 3.

The maximum width of that portion of the striker passing between the anvils shall be at least 10 mm but not greater than 18 mm.

NOTE 1 An example of a method of verifying the geometry of the striker is to make a replica for examination.

NOTE 2 Tests carried out with the 2 mm and 8 mm strikers usually give different results.

6.4.8 The angle between the line of contact of the striker and the horizontal axis of the test piece shall be 90° ± 2° (see 6.3.6).

6.4.9 The mechanism for releasing the pendulum from its initial position shall operate freely and permit release of the pendulum without initial impulse, retardation or side vibration.

6.4.10 If the machine has a brake mechanism, means shall be provided to prevent the brake from being accidentally engaged. In addition, there shall be provision to disengage the brake mechanism, for example during the measurement of period and friction losses.

6.4.11 Machines with automated lifting devices shall be constructed so that direct verification can be performed.

6.5 Anvil and supports

6.5.1 Inspection of the anvils and supports should consist of determining the following items (see Figures 2 and 3 and Table 3):

a) configuration of the supports;

b) configuration of the anvils;

c) distance between the anvils;

d) taper of the anvils;

e) radius of the anvils;

f) clearance for the broken test piece to exit the machine.

6.5.2 The planes containing the support surfaces shall be parallel and the distance between them shall not exceed 0,1 mm. Supports shall be such that the axis of the test piece is parallel to the axis of rotation of the pendulum within 3/1 000.

6.5.3 The planes containing the anvils shall be parallel and the distance between them shall not exceed 0,1 mm. The two planes containing the supports and the anvils shall be 90° ± 0,1° relative to each other. Additional requirements for the configuration of the anvils are given in Table 3.

6.5.4 Sufficient clearance shall be provided to ensure that fractured test pieces are free to leave the machine with a minimum of interference and not rebound into the hammer before the pendulum completes its swing. No part of the pendulum that passes between the anvils shall exceed 18 mm in width.

Hammers are often of one of two basic designs (see Figure 1). When using the C-type hammer, the broken test pieces will not rebound into the hammer if the clearance at each end of the test piece is greater than 13 mm. If end stops are used to locate test pieces, they shall be retracted prior to the instant of impact. When using the U-type hammer, means shall be provided to prevent the broken test pieces from rebounding into the hammer. In most machines using U-type hammers, shrouds (see Figure 3) should be designed and installed with the following requirements:

a) a thickness of approximately 1,5 mm;

b) a minimum hardness of 45 HRC;

c) a radius of at least 1,5 mm at the underside corners;

d) a position in which the clearance between them and the hammer overhang does not exceed 1,5 mm.

In machines where the opening within the hammer permits a clearance between the ends of the test piece (resting in position ready to test) and the shrouds of at least 13 mm, the requirements of a) and d) need not apply.

6.6 Indicating equipment

6.6.1 The verification of the analogue indicating equipment shall consist of the following examinations:

a) examination of the scale graduations;

b) examination of the indicating pointer.

The scale shall be graduated in units of angle or of energy.

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 indicating pointer shall permit a reading free from parallax.

The resolution, r, of the indicator is 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 are 1:4, 1:5, or 1:10; a spacing of 2,5 mm or greater is required to estimate a tenth of a division on the scale.

The scale interval shall be at most 1 % of the nominal energy and shall permit an estimation of energy in increments of better than 0,25 % of the nominal energy.

6.6.2 The verification of digital indicating equipment shall ensure that the following requirements are met.

— The scale shall be graduated in units of angle or of energy.

— The resolution of the scale is considered to be one increment of the last active number of the digital indicator provided that the indication does not fluctuate by more than one increment. When the readings fluctuate by more than one increment, the resolution is taken to be equal to half the range of fluctuation.

— The resolution shall be better than 0,25 % of the nominal energy.

7 Indirect verification by use of reference test pieces

7.1 Reference test pieces used

Indirect verification consists of verifying points on the measuring scale using reference test pieces. These reference test pieces are used:

a) for comparison between test results obtained with the machine under consideration and test results obtained with a particular reference machine or set of reference machines, or with an ISO 148 traceable K value;

b) to monitor the performance of a machine over a period of time, without reference to any other machine.

7.2 Absorbed energy levels

The indirect verification shall be performed at a minimum of two absorbed energy levels within the range of use of the machine. A set for each energy level shall consist of at least five reference test pieces. The reference-test-piece absorbed energy levels shall be as close as possible to the upper and lower limits of the range of use subject to the availability of reference test pieces for these absorbed energy levels.

When more than two reference-test-piece absorbed energy levels are used, the other level(s) should be distributed as uniformly as possible between the upper and lower limits subject to the availability of reference test pieces.

7.3 Requirements for reference test pieces

The requirements for the reference test pieces are found in ISO 148-3.

7.4 Limited direct verification

A limited direct verification shall be performed before each indirect verification. This limited direct verification includes:

a) inspection of the machine in accordance with 6.2.3 a);

b) inspection (visual at least) of the striker and anvils for excessive wear (see Table 3);

c) measurement of the gap (see Table 3);

d) measurement of the angularity, only when the striker or supports are changed (see Table 3);

e) measurement of the losses due to bearing friction and air resistance;

f) measurement of the loss due to pointer friction.

7.5 Bias and repeatability

7.5.1 Repeatability

KV_1, KV_2, ..., $KV_{n\text{V}}$ are the absorbed energies at rupture of the n_V reference test pieces of a set numbered in order of increasing value. The repeatability of the machine under the particular controlled conditions is characterized by the number

$$b = KV_{n\text{V}} - KV_1 \text{, i.e. } KV_{\text{max}} - KV_{\text{min}} \tag{14}$$

The maximum allowed repeatability values are given in Table 2.

7.5.2 Bias

The bias of the machine under the particular controlled conditions is characterized by the number

$$B_\text{V} = \overline{KV}_\text{V} - KV_\text{R} \tag{15}$$

where

$$\overline{KV}_\text{V} = \frac{\sum KV_i + \ldots + KV_{n\text{V}}}{n_\text{V}} \tag{16}$$

The maximum allowed bias values are given in Table 2.

Table 2 — Maximum allowed values for repeatability and bias values

Values in joules

Absorbed energy level	**Repeatability** b	Bias $\lvert B_\text{V} \rvert$
< 40	$\leqslant 6$	$\leqslant 4$
$\geqslant 40$	$\leqslant$ 15 % KV_R	$\leqslant$ 10 % KV_R

8 Frequency of verification

8.1 An indirect verification including a limited direct verification shall be performed at the time of installation or after moving the machine.

8.2 When parts which are subject to wear are replaced, a direct verification in accordance with clauses describing the affected part(s) shall be performed. An indirect verification shall also be performed.

8.3 Indirect verifications shall be performed at intervals not exceeding 12 months.

8.3.1 More frequent indirect verifications may be necessary based on one or more of the following:

a) a large number of tests have been performed;

b) the absorbed energy required to fracture the individual test pieces is large compared to the nominal energy;

c) the quality management system established by the test house requires more frequent indirect verification.

8.3.2 Indirect verification shall be performed after changing the strikers.

8.4 Direct verification shall be performed when the machine is new and when the results of an indirect verification are unsatisfactory (see Clause 1). A limited direct verification shall be performed prior to performing an indirect verification (see 7.4).

8.5 The procedures given in 6.4.5.1 and 6.4.5.2 should be performed at the beginning of each day during which the machine is used because they provide a quick indication as to whether the performance of the machine has been impaired, e.g. by dirt in the bearings.

9 Verification report

9.1 General

The report of verification shall include at least the following information:

a) reference to this part of ISO 148, i.e. ISO 148-2:2008;

b) identification of the machine: manufacturer's name, model and serial number;

c) radius of striker;

d) name of owner and address of place of installation;

e) name or mark of organization performing the verification;

f) date of the verification.

9.2 Direct verification

The following information on the direct verification of the machine shall be included:

a) nominal energy of the pendulum;

b) velocity of pendulum at impact;

c) absorbed energy lost due to air resistance and friction.

9.3 Indirect verification

The following information on indirect verification of the machine shall be included:

a) identification of the reference test pieces used in the indirect verification, including the reference values and the actual observed absorbed energy values for these test pieces;

b) results of the indirect verification:

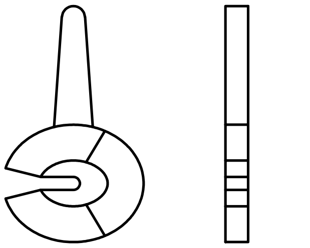
   1) repeatability;

   2) bias;

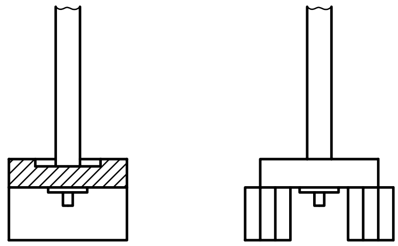
   3) a statement that the machine does or does not conform to the requirements of this part of ISO 148.

10 Uncertainty

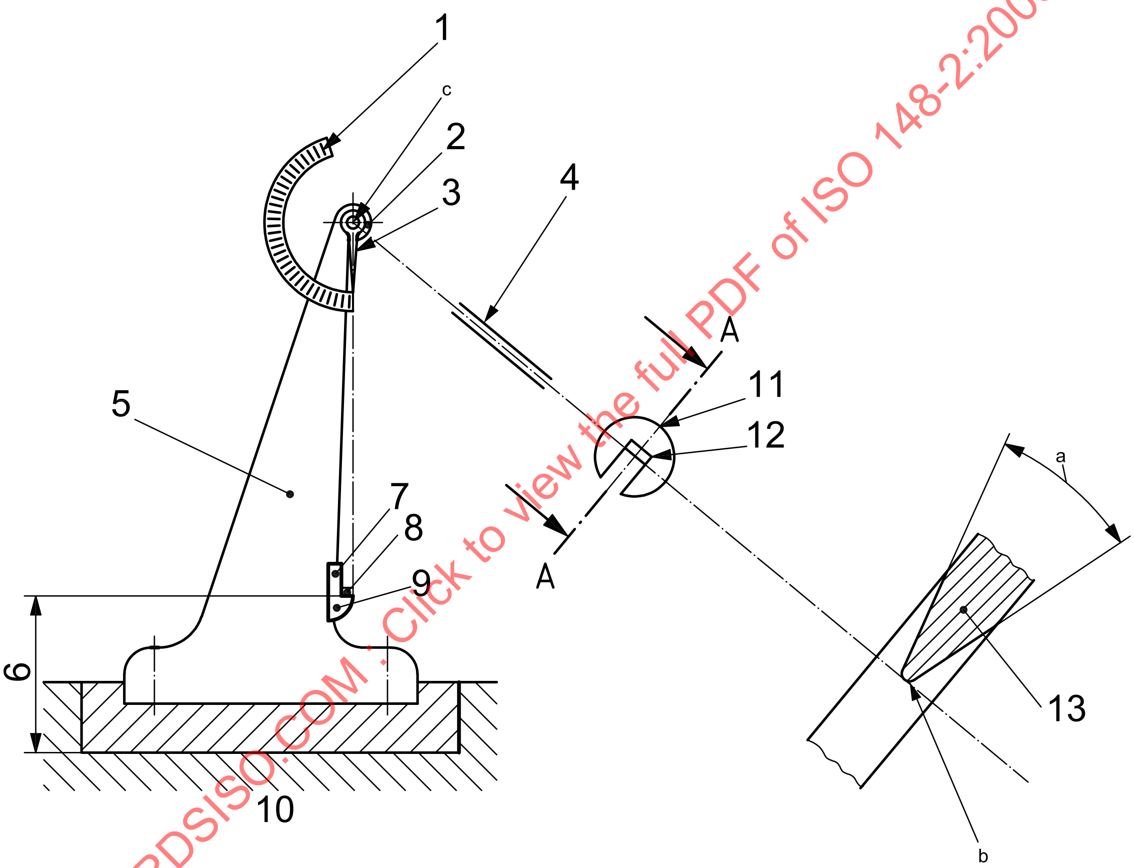
A method for calculating uncertainty is given in Annex A.



a) C-type hammer



b) U-type hammer



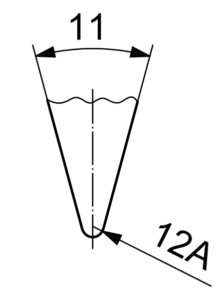
c) Test machine

Key

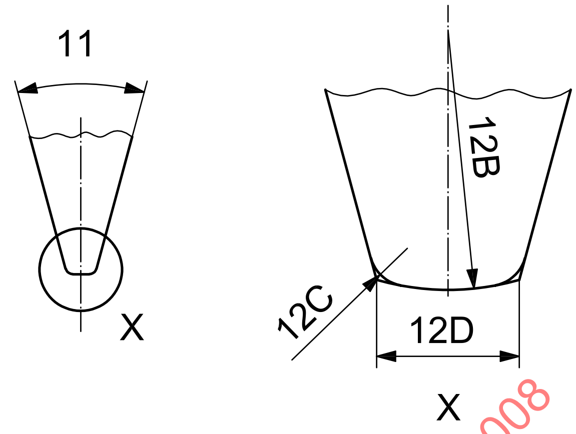
1 scale
2 pendulum bearings
3 friction pointer
4 pendulum rod
5 machine framework
6 base
7 anvil
8 test piece
9 test-piece supports
10 foundation
11 C-type hammer
12 edge of striker
13 striker

a Angle of striker.
b Radius of curvature of edge of striker.
c Axis of rotation.

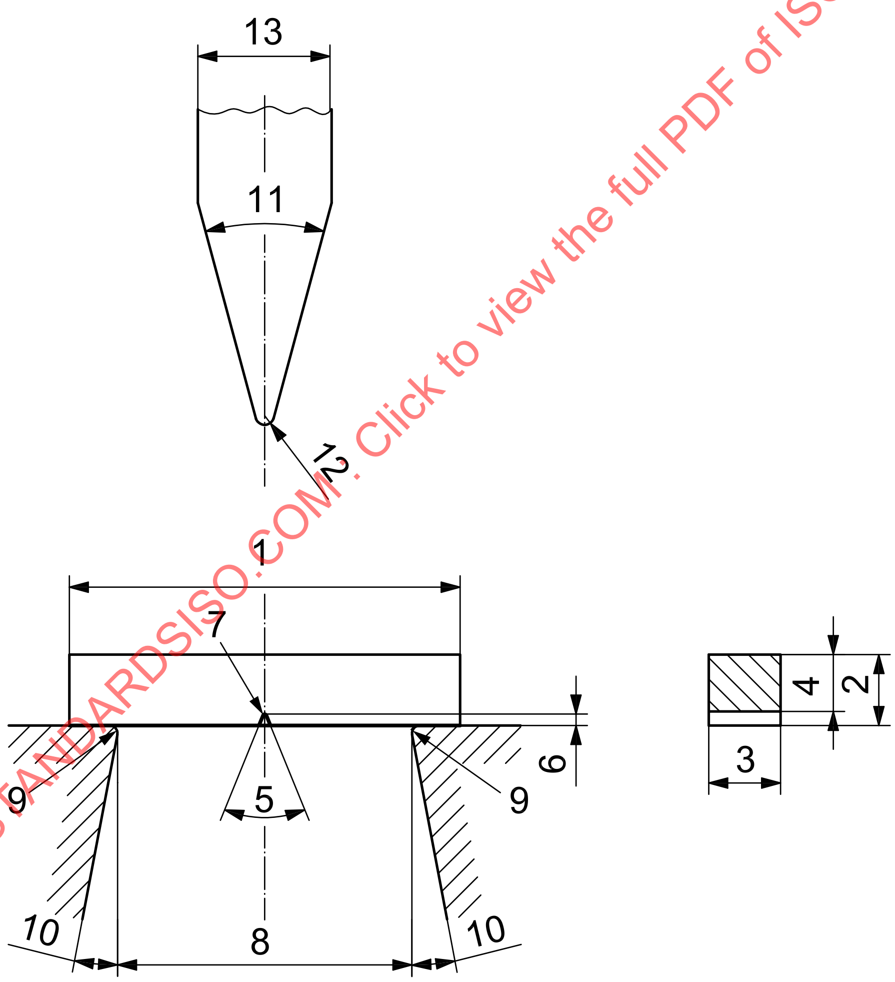
Figure 1 — Parts of a pendulum-type impact test machine



a) 2 mm striker



b) 8 mm striker



c) Overview

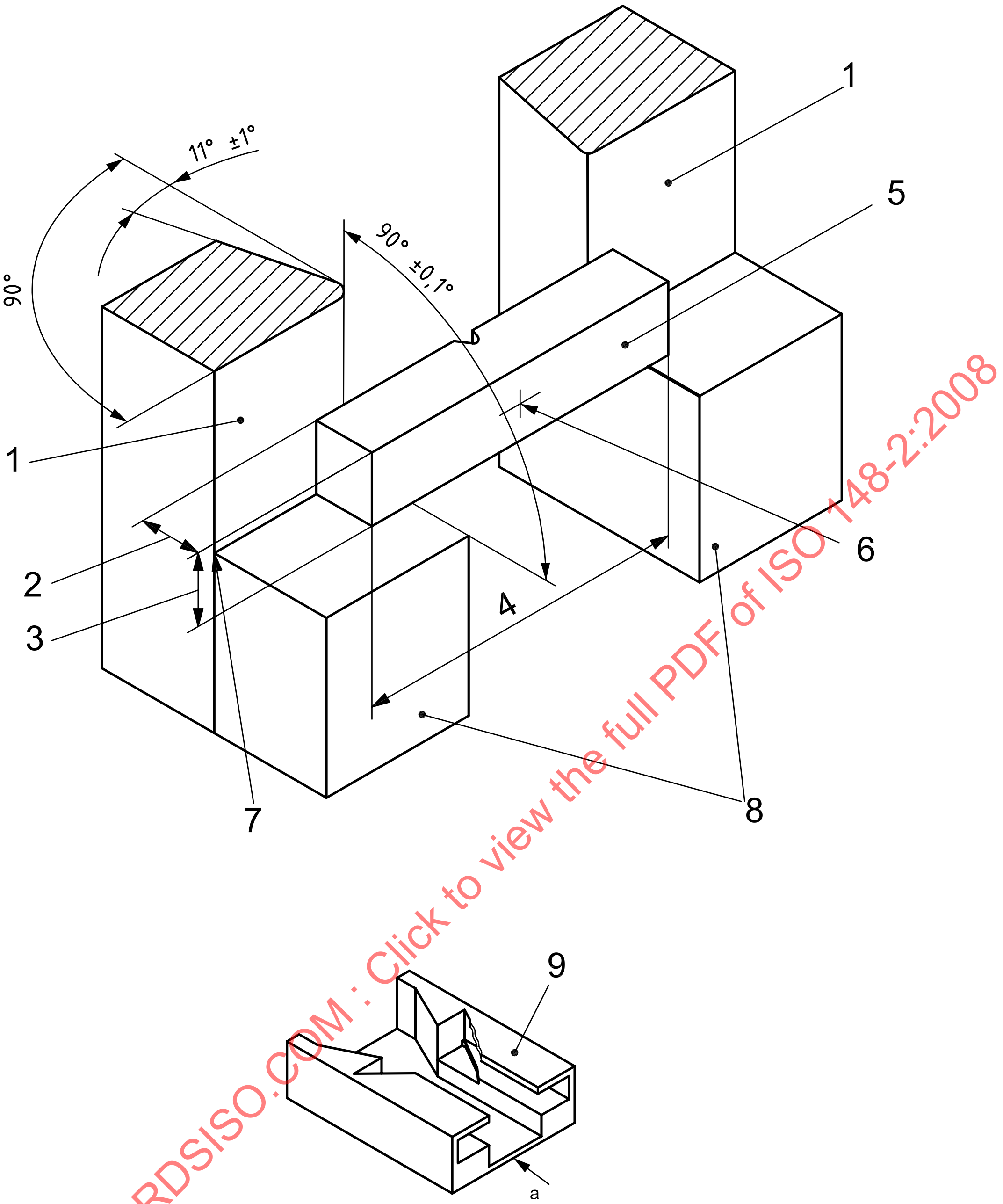
NOTE See Table 3 for geometrical characteristics.

Figure 2 — Strikers, test-piece supports and anvils of pendulum-type impact test machines

Table 3 — Geometrical characteristics

Number [a]	Designation	Size
1	Length of test piece	see ISO 148-1
2	Height of test piece	see ISO 148-1
3	Width of test piece	see ISO 148-1
4	Height of test piece minus depth of notch (height below notch)	see ISO 148-1
5	Angle of notch	see ISO 148-1
6	Depth of notch	see ISO 148-1
7	Radius of curvature of base of notch	see ISO 148-1
8	Distance between anvils	$\left(40 {}^{+0,20}_{0,00}\right)$ mm
9	Radius of anvils	$\left(1 {}^{+0,50}_{0,00}\right)$ mm
10	Angle of taper of anvil	11° ± 1°
11	Angle of striker	30° ± 1°
12	Radius of curvature of edge of striker:	
12A	2 mm striker	2,00 mm to 2,50 mm
12B	8 mm striker	8 mm ± 0,05 mm
12C	Radius of shoulder of 8 mm striker	0,25 mm ± 0,05 mm
12D	Width of edge of 8 mm striker	4 mm ± 0,05 mm
13	Width of striker	10 mm to 18 mm

[a] See Figure 2.

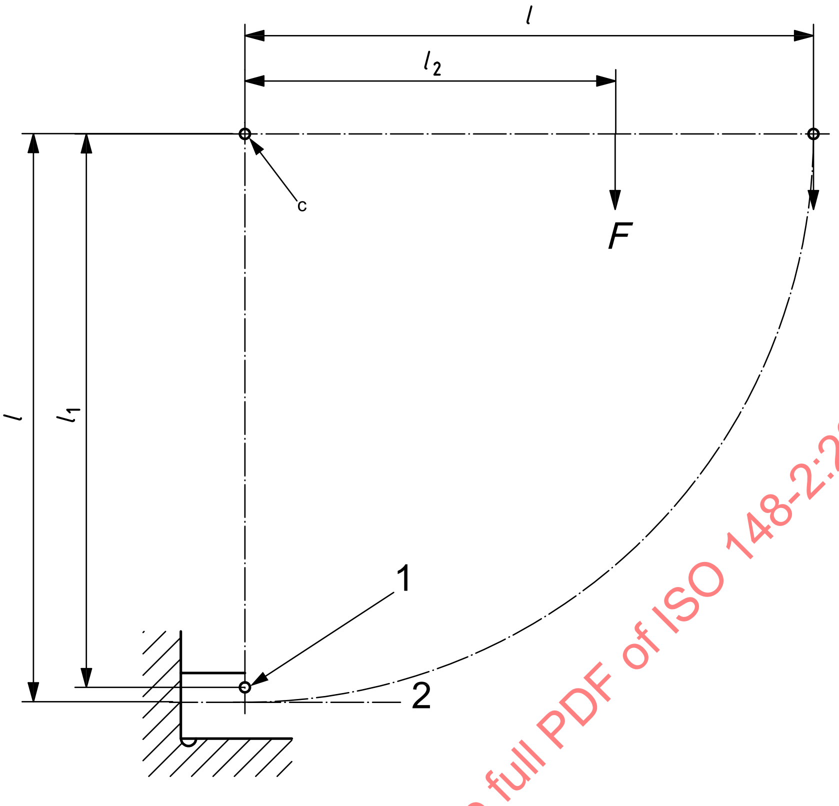


Key

1 anvil
2 height of test piece
3 width of test piece
4 length of test piece
5 standard-size test piece
6 centre of strike
7 recess
8 test-piece supports
9 shroud

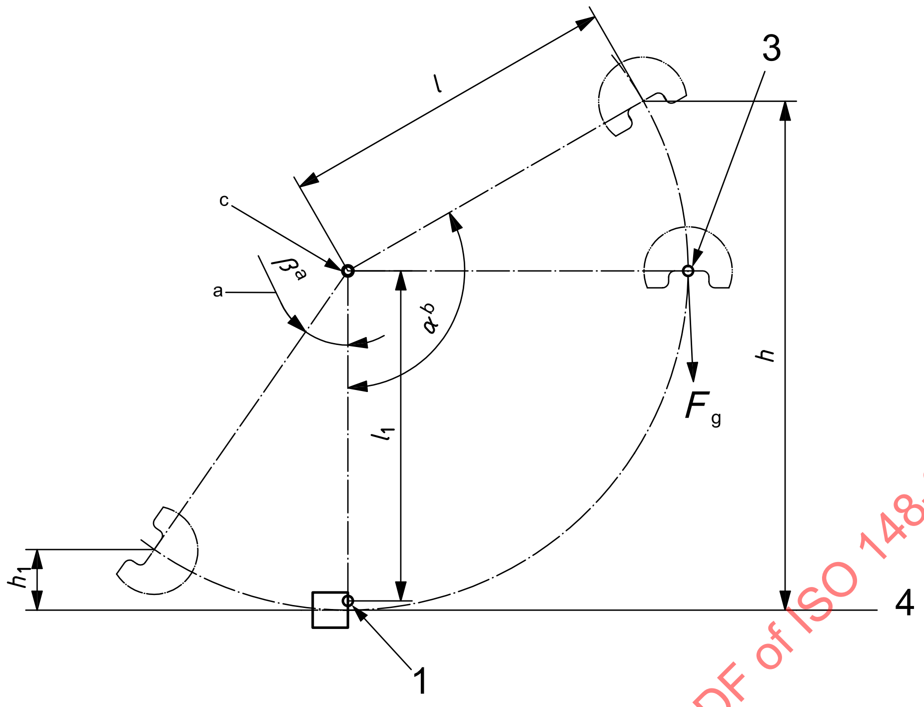
a Direction of pendulum swing.

Figure 3 — Configuration of test piece supports and anvils of an industrial pendulum-type impact test machine



a) Determination of moment, M

Figure 4 (*continued*)



b) Designation of terms used to determine energy

Key

1 centre of percussion

2 centre of test piece

3 centre of strike of pendulum

4 centre of standard-size test

a Angle of vise, β.

b Angle of fall, α.

c Axis of rotation.

Figure 4 — Determination of the initial potential energy

Annex A
(informative)

Measurement uncertainty of the result of the indirect verification of a Charpy pendulum impact machine

A.1 Scope and general requirements

A.1.1 General

This informative annex provides a method for determining the uncertainty associated with the results of indirect verification tests of a Charpy pendulum impact machine. Other methods for assessing the uncertainty of these tests can be developed and are acceptable, if they meet the requirements of the GUM (see Reference [9]).

This annex proposes a systematic approach, which leads to estimates for B_V (the bias of the instrument) and u_V (the uncertainty of the overall indirect verification result). The values of these parameters are required for the calculation of the measurement uncertainty of the results of tests performed with the pendulum impact testing machine after the verification, as described in ISO 148-1.

NOTE ISO 148-1:2006, Annex A, also provides a general scheme of the metrological chain used to disseminate absorbed energy scales through indirect verification using reference test pieces.

A.1.2 Uncertainty disclaimer

Measurement uncertainty analysis is useful for identifying major sources of inconsistencies of measured results.

Product standards and material property databases based on this and earlier versions of this part of ISO 148 have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk failing compliant product. For this reason, the estimates of uncertainty derived by following this procedure are for information only, unless specifically instructed otherwise by the customer.

The test conditions and limits defined in this part of ISO 148 shall not be adjusted to take account of uncertainties of measurement, unless specifically instructed otherwise by the customer. The estimated measurement uncertainties shall not be combined with measured results to assess compliance to product specifications, unless specifically instructed otherwise by the customer.

A.2 Contributions to the uncertainty of the indirect verification result

A.2.1 Bias

The primary result of an indirect verification is the estimate of the instrument bias, B_V:

$$B_V = \overline{KV}_V - KV_R \tag{A.1}$$

where

$\overline{KV}_{\text{V}}$ is the mean value of the reference test pieces broken during the indirect verification;

KV_{R} is the certified KV value of the reference test pieces.

The absolute value of B_{V} shall meet the criteria set in Clause 7.

A.2.2 Uncertainty of the bias value

The standard uncertainty of the bias value is equal to the combined standard uncertainties of the two terms in Equation (A.1).

u_{RM}, the standard uncertainty of the certified reference value, KV_{R}, is calculated from the expanded uncertainty, U_{RM}, indicated on the certificate of the reference test pieces, by dividing U_{RM} with the appropriate coverage factor (also indicated on the certificate).

The uncertainty associated with $\overline{KV}_{\text{V}}$ is calculated as:

$$u(\overline{KV}_{\text{V}}) = \frac{s_{\text{V}}}{\sqrt{n_{\text{V}}}} \tag{A.2}$$

where s_{V} is the standard deviation of the results of the n_{V} reference test pieces. Subclause 7.2 prescribes the use of five reference test pieces for the indirect verification.

NOTE Equation (A.2) shows that choosing a larger number n_{V} can be used to reduce the measurement uncertainty.

Therefore, $u(B_{\text{V}})$, the standard uncertainty of B_{V}, is calculated as:

$$u(B_{\text{V}}) = \sqrt{\left(\frac{s_{\text{V}}}{\sqrt{n_{\text{V}}}}\right)^2 + u_{\text{RM}}^2} \tag{A.3}$$

A.3 Determining the combined uncertainty of the indirect verification result, u_{V}

As a general rule, bias should be corrected for. However, due to wear of the anvil and hammer parts, it is difficult to obtain a perfectly stable bias value throughout the period between two indirect verifications. This is why the measured bias value is considered an uncertainty contribution, to be combined with its own uncertainty to obtain the uncertainty of the indirect verification result, u_{V}:

$$u_{\text{V}} = \sqrt{u^2(B_{\text{V}}) + B_{\text{V}}^2} \tag{A.4}$$

To correct the absorbed energy values measured with a pendulum impact testing machine, add a term equal to $-B_{\text{V}}$. This requires that the bias value be firmly established and stable. Such level of knowledge on the performance of a particular pendulum impact testing machine can only be achieved after series of indirect verification and control chart tests, which should provide the required evidence about the stability of the instrument bias. Therefore, the practice is likely to be limited to reference pendulum impact testing machines.

A.4 Expanding the combined uncertainty

The value of u_V is used in ISO 148-1:2006/Amd.1:—[1], Annex E, as one of the contributions to total measurement uncertainty. To expand a combined standard uncertainty, the degrees of freedom of the respective uncertainty contributions need to be combined into effective degrees of freedom. The degrees of freedom of u_V are calculated using the Welch-Satterthwaite approximation:

$$\nu_V = \frac{u_V^4}{\dfrac{u^4\left(\overline{KV}_V\right)}{\nu_B} + \dfrac{u_{RM}^4}{\nu_{RM}} + \dfrac{B_V^4}{\nu_B}} \qquad \text{(A.5)}$$

The value of ν_B equals $n_V - 1$; the value of ν_{RM} is taken from the reference materials' certificate.

The number of verification test samples is most often five, and the heterogeneity of the samples is not insignificant. This is why the number of effective degrees of freedom is most often not large enough to use a coverage factor of k equal to 2. Other values of k may be used if interested parties are in agreement.

A.5 Examples of B_V and u_V calculation and reporting

This clause presents an example of an indirect verification result and its analysis. The presumed indirect verification is executed after a direct verification, using reference test pieces of three different energy levels. The results presented are those obtained on reference test pieces with a certified KV_R value of 123,8 J, and an expanded uncertainty of 3,4 J, with 28 degrees of freedom (values taken from the RM certificate).

Table A.1 — Example — Results of the indirect verification tests

Test results and data from certificates		Calculation of bias and uncertainty values	
Sample 1	123,1 J	$\overline{KV}_V$	119,4 J
Sample 2	116,1 J	s_V	4,7 J
Sample 3	112,8 J	n_V	5
Sample 4	123,6 J	From Equation (A.2): $u\left(\overline{KV}_V\right)$	2,1 J
Sample 5	121,3 J		
From certificate: degrees of freedom, ν_{RM}	30	From Equation (A.1): B_V	–4,4 J
From certificate: expanded uncertainty at a confidence level of about 95 %, U_{RM}	3,4 J	From Equation (A.3): $u(B_V)$	2,7 J
Since $\nu_{RM} > 10$, u_{RM}, the standard uncertainty, can be calculated as $U_{RM}/2$	1,7 J	From Equation (A.4): u_V	5,2 J
Degrees of freedom for 5 samples, ν_B	4	From Equation (A.5): ν_V	7

1) To be published.

The primary result of the indirect verification is good: the absolute value of the bias (B_V = –4,4 J) is below the upper threshold set in Clause 7. The value of B_V needs to be combined with its uncertainty to obtain u_V, unless its value is well established, which we do not consider to be the case here. From Equation (A.5), the number of degrees of freedom corresponding to u_V is calculated to be 7. The verification results can be reported as shown in Table A.2.

Table A.2 — Summary table of the result $\overline{KV}$ with expanded measurement uncertainty, $U(\overline{KV})$

KV_R J	B_V J	$u(B_V)$ J	ν_V	u_V J
123,8	–4,4	2,7	7	5,2
	B_V is not firmly established.			
…[a]	…	…	…	…
	…			

[a] This summary table contains one row for each of the energy levels at which the pendulum was indirectly verified.

A graphical representation of the example is given in Figure A.1, together with the results obtained if the measured absorbed energy values are corrected for the measured bias. The uncertainty of the indirect verification is relatively large (u_V = 5,2 J) as it consists of the combination of $u(B_V)$ and B_V. If the bias value had been better established, and the measured value corrected for its value, a considerably smaller uncertainty could have been obtained [$u(B_V)$ = 2,7 J].

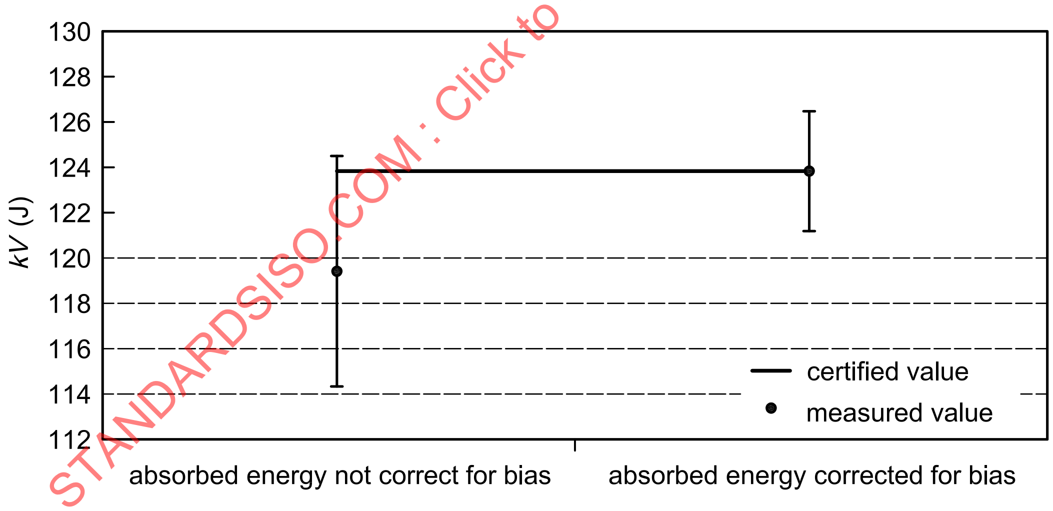


Figure A.1 — Graphical representation of the default approach (left) **with an uncorrected absorbed energy and the associated uncertainty, u_V, as well as the case where the measured value is corrected for the bias** (right)**, giving a smaller uncertainty, $u(B_V)$**

Annex B
(informative)

Measurement uncertainty of the results of the direct verification of a Charpy pendulum impact testing machine

B.1 Scope

Direct verification consists of a series of checks of geometrical and mechanical features of a pendulum impact testing machine. Deviation from the nominal values of these features contributes to the bias of the instrument with respect to the expected behaviour of a pendulum impact testing machine built in perfect accordance with Clause 6.

In theory, one can use an equation such as the following for the estimation of z, the combined instrument bias:

$$z = R + A + C + E + V + (l - l_1) + H + S \quad \text{(B.1)}$$

where

- R is the bias in K (in energy units) due to bias of the radius of tup or striker;
- A is the bias in K (in energy units) due to bias of anvil and supports geometry;
- C is the bias in K (in energy units) due to bias of the centre of strike;
- E is the bias in K (in energy units) due to the energy calculation from measured angles;
- V is the bias in K (in energy units) due to bias of the impact velocity;
- $(l - l_1)$ is the bias in K (in energy units) due to bias of the difference between pendulum length and centre of percussion;
- H is the bias in K (in energy units) due to the correction for friction loss;
- S is the bias in K (in energy units) due to the bias of the energy read from an analogue or digital scale.

The effects the factors (R, A, C, E, V, $l - l_1$, H, S) on the absorbed energy are assumed to be small if they are within the tolerances required for direct verification of the machine (see Clause 6), and if the pendulum impact test is performed according to the standard procedure (see ISO 148-1). However, there are uncertainties associated with the assessment of the individual factors contributing to z. Assuming that all quantities are independent, the combined standard uncertainty of z would be

$$u_c(z) = \sqrt{u^2(R) + u^2(A) + u^2(C) + u^2(E) + u^2(V) + u^2(l - l_1) + u^2(H) + u^2(S)} \quad \text{(B.2)}$$

Not all the elements from Equation (B.1) and Equation (B.2) can be reliably and quantitatively assessed. Instead, indirect verification of the instrument, with reference materials, is used to assess the bias of a pendulum and the associated uncertainty.

Nevertheless, it remains important to consider the reliability of the different steps in the mandatory direct verification. This is why this informative annex discusses state-of-the-art methods to determine the uncertainties associated with the results of a number of measurements performed during the direct verification of a Charpy pendulum impact machine.

Usually, the uncertainty of a certified value on the certificate is specified for a confidence level of about 95 %. Therefore, the standard combined uncertainty, u_{RM}, has to be expanded using an appropriate coverage factor, k. The coverage factor to be used depends on the number of degrees of freedom associated with the combined uncertainty, which can be computed using the Welch-Satterthwaite approximation. For a typical case, the number of effective degrees of freedom is larger than 20 and a coverage factor of k = 2 can be used.

NOTE 1 Other methods to assess the measurement uncertainties can be developed and are acceptable if they meet the requirements of the GUM (see Reference [9]).

The ultimate aim is to achieve a reliable estimate of the measurement uncertainty for the directly verified features so as to verify whether the sum of the deviation between the nominal and the measured value and the measurement uncertainty of this deviation is within the tolerances allowed by Clause 6.

NOTE 2 Uncertainty disclaimer note:

Measurement uncertainty analysis is useful for identifying major sources of inconsistencies of measured results.

Product standards and material property databases based on this and the previous version of this part of ISO 148 have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk failing compliant product. For this reason, the estimates of uncertainty derived by following this procedure are for information only, unless specifically instructed otherwise by the customer.

The test conditions and limits defined in this part of ISO 148 shall not be adjusted to take account of uncertainties of measurement, unless specifically instructed otherwise by the customer. The estimated measurement uncertainties shall not be combined with measured results to assess compliance with product specifications, unless specifically instructed otherwise by the customer.

B.2 Uncertainty for particular instrument parameters

B.2.1 Centre of percussion

The pendulum must be constructed in a way that makes pendulum length, l, equal to the distance between the centre of percussion and the axis of rotation, l_1.

For the determination of l_1, the following equation is valid:

$$l_1 = \frac{gt^2}{4\pi^2} \tag{B.3}$$

where

l_1 is the distance between the position of the centre of percussion and the axis of rotation (reduced pendulum length), in metres;

t is the average period of swing of pendulum from three measurements at 100, 50 or 25 swings.

The time measurement T, e.g. for 50 swings, is carried out manually or by a calibrated time-measuring device. In this example, a realistic measurement uncertainty of $u(T)$ = 0,1 s will be used. The uncertainty of l_1 can then be calculated as

$$u(l_1) = \frac{2gT}{(4\pi^2)\cdot 50^2} \cdot u(T) \tag{B.4}$$

The pendulum length, l, is measured with callipers. Because l can often not measured directly, it is determined by three partial measurements L_1, L_2 and L_3, which means:

$$u(l) = \sqrt{u^2(L_1) + u^2(L_2) + u^2(L_3)} \quad \text{(B.5)}$$

Callipers for smaller lengths (e.g. L_1 and L_3) usually have a measurement uncertainty of 0,1 mm. Callipers for the larger length (here L_2) typically have a measurement uncertainty of 0,3 mm. In this case, the combined uncertainty $u(l)$ = 0,3 mm.

NOTE These values are typically included on the calibration certificate of the instrument used.

The measurement uncertainty of the deviation of the position of the centre of percussion from the measured pendulum length, $(l - l_1)$, is calculated with the above-given uncertainties as follows:

$$u(l - l_1) = \sqrt{u^2(l) + u^2(l_1)} \quad \text{(B.6)}$$

EXAMPLE See also Table B.1.

For a measured pendulum length l = 800,0 mm, a measured T (50 swings) = 89,7 s, and the resulting calculated value for l_1 = 799,75 mm, and using the above uncertainties for length and time measurements, an uncertainty $u(l - l_1)$ of 1,07 mm is obtained. This is within the tolerance (0,5 %) allowed.

Table B.1 — Measurement uncertainty of position of centre of percussion

Quantity	Estimated value	Uncertainty		Standard uncertainty	Sensitivity coefficient	Contribution to uncertainty of $(l - l_1)$
		Value	Distribution type			
l	800,0 mm	0,3 mm	Normal	0,3 mm	1 mm/mm	0,3 mm
T	89,7 s	0,1 s	Rectangular	0,058 s	17,83 mm/s	1,03 mm
Combined measurement uncertainty $u(l - l_1)$						1,07 mm
Expanded measurement uncertainty using k = 2 for a 95 % confidence level						2,14 mm

B.2.2 Impact velocity

The impact velocity is calculated from the pendulum length and the fall angle and is a typical parameter of the testing machine. The permissible errors specified in this International Standard for the direct verification are relatively large. Therefore, calculation of the uncertainty of its value is not required.

B.2.3 Absorbed energy calculation

For the calculation of the absorbed energy, the following measurement equation is valid:

$$KV = F \times l_2 \times (\cos\beta - \cos\alpha) \quad \text{(B.7)}$$

where

- K is the absorbed energy as calculated from measured fall and rise angles, in joules;
- F is the force exerted by the pendulum in the horizontal position on the force-proving device for distance l_2, in newtons;
- l_2 is the distance between the point of application of force F and the axis of rotation, in metres;
- α is the angle of fall, in degrees;
- β is the angle of rise, in degrees.

The above parameters are not bound by certain nominal values or ranges in the standard. Therefore, there is no bias associated with these parameters, only a measurement uncertainty. The uncertainty of the energy calculated from the measured values is expressed as:

$$u_1^2 = \left(\frac{\partial KV}{\partial F}\right)^2 u^2(F) + \left(\frac{\partial KV}{\partial l_2}\right)^2 u^2(l_2) + \left(\frac{\partial KV}{\partial \beta}\right)^2 u^2(\beta) + \left(\frac{\partial KV}{\partial \alpha}\right)^2 u^2(\alpha) \quad \text{(B.8)}$$

From Equation (B.7), the following can be derived:

$$\frac{\partial KV}{\partial \alpha} = F \cdot l_2 \cdot \sin\alpha \quad \text{(B.9)}$$

$$\frac{\partial KV}{\partial \beta} = -F \cdot l_2 \cdot \sin\beta \quad \text{(B.10)}$$

$$\frac{\partial KV}{\partial F} = l_2 \cdot (\cos\beta - \cos\alpha) \quad \text{(B.11)}$$

$$\frac{\partial KV}{\partial l_2} = F \cdot (\cos\beta - \cos\alpha) \quad \text{(B.12)}$$

With respect to the individual uncertainty contributions:

$$u(F) = \sqrt{u^2(F_{\text{std}}) + u^2(t) + u^2(S) + u^2(D)} \quad \text{(B.13)}$$

where

$$u(t) = \frac{\delta \cdot a_{\text{temp}}}{\sqrt{3}} \quad \text{(B.14)}$$

where

δ is the temperature coefficient of the working standard (given by the manufacturer);

a_{temp} is the deviation from the reference temperature;

$$u(S) = \frac{a_{\text{stab}}}{\sqrt{3}} \quad \text{(B.15)}$$

where a_{stab} is the long-term stability of the working standard;

$$u(D) = a_{\text{int-dev}} \quad \text{(B.16)}$$

where $a_{\text{int-dev}}$ is the interpolation deviation of the working standard;

$$u(l_2) = \frac{\Delta l_2}{l_2} \quad \text{(B.17)}$$

where Δl_2 is the uncertainty of the distance measurement between the point of application of the force and the axis of rotation.

NOTE Δl_2 is taken from the calibration certificate of the instrument used to measure l_2.

EXAMPLE See also Table B.2.

1) Force

Measurement uncertainty of the force transducer: U_{std} = 0,12 % (k = 2)

Long-term stability of the force transducer: a_{stab} = 0,05 %

Temperature coefficient of the force transducer: δ = 0,01 %

Deviation from the reference temperature: a_{temp} = 5,0 °C

Measurement uncertainty due to linear interpolation

of the force exerted by the pendulum on the force-proving device: $a_{int\text{-}dev}$ = 0,05 %

Force exerted by the pendulum on the force-proving device at a 750,1 mm length of the pendulum: F = 206,70 N

The combined contributions to the force uncertainty reach 0,1 %. For a force F of 206,70 N, the combined standard uncertainty, $u(F)$, is therefore 0,21 N.

2) Pendulum length

Uncertainty of the distance measurement: Δl_2 = 0,3 mm

Length of the pendulum: $l = l_2$ = 750,1 mm

(The uncertainty of the distance l_2, over which the force measurement is carried out, can be applied with $\Delta l_2 = \pm$ 0,3 mm for careful use.)

3) Angles

Uncertainty of the angle measurement: $\Delta\alpha = \Delta\beta$ = 0,2°; rise angle: β = 120°; fall angle: α = 160°

Care must be taken to convert degrees into radians and millimetres into metres prior to applying formulae.

Table B.2 — Budget of measurement uncertainty for the absorbed energy calculation

Quantity	Estimated value	Uncertainty		Standard uncertainty	Sensitivity coefficient	Contribution to uncertainty of KV
		Value	Distribution type			
F	206,7 N	0,21 N	Normal	0,21 N	0,33 J/N	0,07 J
L	750,1 mm	0,3 mm	Rectangular	0,17 mm	91 J/m	0,016 J
β	120°	0,2°	Rectangular	0,12°	134 J/rad	0,27 J
α	160°	0,2°	Rectangular	0,12°	53 J/rad	0,11 J
Combined measurement uncertainty						0,30 J
Expanded measurement uncertainty using k = 2 for a 95 % confidence level						0,6 J

B.2.4 Absorbed energy readings from an analog or a digital scale

S is the bias in the scale mechanism; it indicates the difference between the reading of an absorbed energy from the instrument analog scale or a digital value displayed on the instrument PC, and the calculated energy. S can be deduced for a particular pendulum using the results of direct verification:

$$S = K_S - K_{calc} \tag{B.18}$$

where S is the deviation of the indicated energy, K, from the calculated energy, K_T, both in joules.

The effective uncertainty, $u(S)$, is calculated as follows:

$$u(S) = \sqrt{u^2(K_S) + u^2(K_{calc})} \tag{B.19}$$

where

$$u(K_S) = \frac{a}{2 \cdot \sqrt{3}} \tag{B.20}$$

where a is the resolution of the scale.

EXAMPLE See also Table B.3.

Value read from analog scale:	K_S = 68,0 J
Resolution of the indicator:	a = 0,5 J
Energy value calculated from measured angles:	K_{calc} = 68,17 J
Uncertainty of the energy calculated from measured angles:	$u(K_{calc})$ = 0,38 J

Table B.3 — Measurement uncertainty of the deviation of the indicated absorbed energy

Quantity	Estimated value	Uncertainty		Standard uncertainty	Sensitivity coefficient	Contribution to uncertainty of S
		Value	Distribution type			
K_S	68,0 J	0,5 J	Rectangular	0,14 J	1	0,14 J
K_{calc}	68,17 J	0,3 J	Normal	0,3 J	1	0,3 J
Combined measurement uncertainty						0,33 J
Expanded measurement uncertainty using k = 2 for a 95 % confidence level						0,7 J